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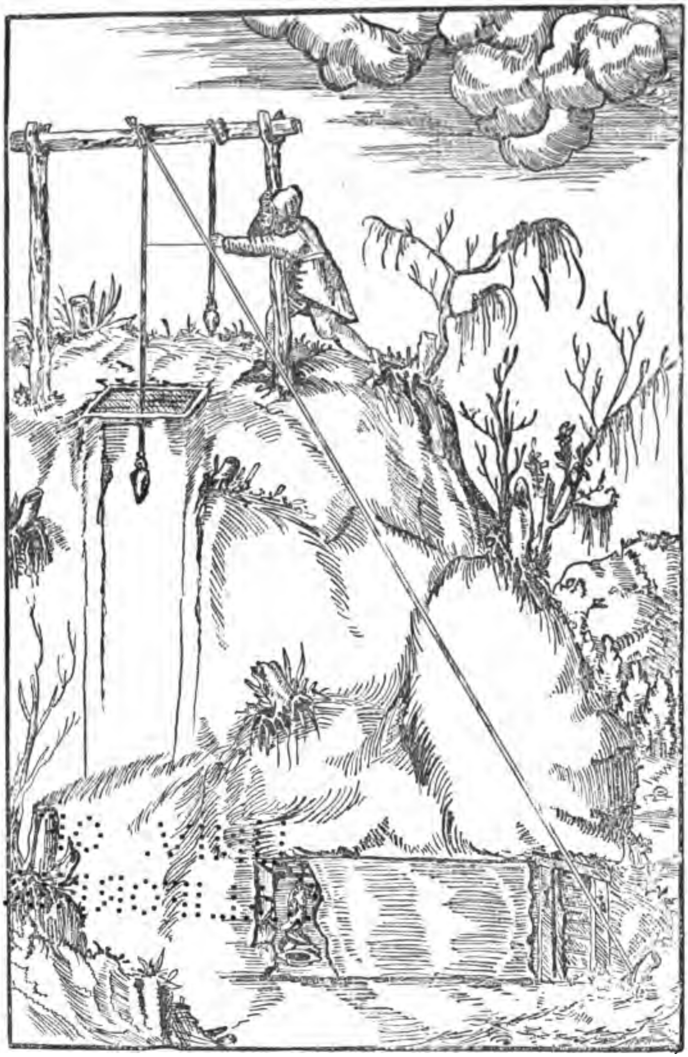

Mine-Surveying in the Middle Ages.

(*Facsimile of a drawing in Agricola's de re Metallica*, 1556.)

A TREATISE

ON

MINE-SURVEYING.

BY

BENNETT H. BROUGH,

ASSOCIATE OF THE ROYAL SCHOOL OF MINES; MEMBER OF COUNCIL OF THE INSTITUTION
OF MINING ENGINEERS; FELLOW OF THE GEOLOGICAL SOCIETY AND OF
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PREFACE TO FIFTEENTH EDITION.

As the Fourteenth Edition of this book was revised throughout and in part re-written, an unusually large number was printed, but these have been quickly sold. Further revision seemed to be unnecessary, since the mining press pronounced the book "a masterly production, practically amounting to a new work." Only a few corrections have, therefore, been made for this edition.

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PREFACE.

No apology is required for any well-considered attempt to provide a manual of Mine-Surveying for the use of English readers. The absence of any general work on the subject has long been a source of practical inconvenience alike to teachers and students. The text-books recommended to candidates for the examination in Mine-Surveying held by the City and Guilds of London Institute, namely, Budge's *Practical Miner's Guide*, published in 1825, and Hoskold's *Practical Treatise on Mining, Land, and Railway Surveying*, published in 1863, are too limited in their scope, the former dealing only with the mines of Cornwall, the latter only with those of the Forest of Dean; besides which both works are out of print, and increasingly difficult to procure.

The present work is intended primarily for students, and embodies the substance of the course of instruction in Mine-Surveying given at the Royal School of Mines. At the same time, it will also, it is hoped, be found useful as a companion to the standard works of reference on Land-Surveying.

In the plan of the book, the surveying of collieries and that of metalliferous mines do not receive separate treatment. The two have much in common, and the one may often advantageously borrow a method from the other. Few mine-surveyors in Great Britain appear to be acquainted with the methods and instruments used abroad. This is the more to be regretted, as no mine-surveys made in this country approach in accuracy those of the collieries of Pennsylvania, or those of the metalliferous mines of the Harz. Attention therefore has been directed to the recent improvements in foreign practice. With the exception of a few diagrams borrowed from Professor Rankine's *Manual of Civil Engineering*, the figures elucidating the text have been specially drawn for this book.

The Appendix of examination-questions and exercises for plotting has been culled from recent papers set at the examinations of the Science and Art Department, of the City and Guilds of London Institute, of the local boards under the Home Office for granting certificates of competency to Colliery Managers, and of various Mining Schools. These will, it is trusted, be found of use to such students as have not the advantage of regular instruction in the subject. It must, however, be borne in mind that the mere reading of a text-book will never make a mine-surveyor. The most that a book can do is to help the student to obtain a knowledge of the theory of the subject. The mechanical manipulation of the instruments can only be learnt under the personal supervision of a teacher, whilst the technical skill requisite for carrying out subterranean surveys must be obtained in the mine itself.

I have taken for granted on the part of my readers an elementary knowledge of mathematics, such, for example, as would enable them to pass the second stage of the Science and Art Department's examination in that subject.

In the preparation of the work, I have received valuable help from numerous friends at home and abroad. In particular, I am indebted to Mr. H. W. Hughes, Assoc.R.S.M., F.G.S., for several important additions to the text, and to Mr. A. Pringle, M.A., B.Sc., who ably assisted me while the volume was passing through the press.

BENNETT H. BROUGH.

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LONDON, *February*, 1888.

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UNIV. OF CALIFORNIA

A TREATISE

ON

MINE-SURVEYING.

CHAPTER I.

General Explanations.

Surveying is the art of making such measurements as are necessary to determine the relative positions of any points on the earth's surface. From such measurements a map, or plan, of any portion of the surface may be drawn, and its area calculated.

The branch of surveying specially applied to mining is known as Mine-surveying. It consists in measuring, with a view to subsequent delineation on a plan and sections, first, the underground workings of a mine, and, secondly, the mine-buildings at the surface and the mine-concession or royalty. Thirdly, it requires an accurate method of connecting the underground- and surface-surveys. Trustworthy plans and sections are of value for giving a condensed view of all the facts connected with the works and explorations of a mine; for affording data to assist in the further prosecution of workings after temporary abandonment of the excavations; and for the avoiding of destructive and lamentable effects—such, *e.g.*, as disastrous litigation respecting trespass on adjoining royalties, loss caused by driving in the wrong direction, or irruptions of water, quicksand, or firedamp, giving rise to loss of life and property—which have too often resulted from incorrect or imperfect mine-plans.

Historical Sketch.—The origin of mine-surveying must be sought with that of mining in very early times. The oldest mine-plan known is a papyrus, preserved in the museum at

Turin, depicting the situation of an Egyptian gold-mine. It was drawn in the reign of the king Mineptah, 1,400 years before the Christian era. Land-surveying was first practised in Egypt. There the annual overflows of the Nile, and the consequent deposit of mud, destroyed the land-marks of the different proprietors, so that it became necessary to determine them by measurement every year. The oldest evidence of the solution of mathematical problems is afforded by a papyrus in the British Museum, which is believed to have been copied, 1,700 years B.C., from a much older work. It gives rules for the calculation of areas of triangles, trapezoids, and circles.

That the important mines of the ancient Greeks necessitated the solution of mine-surveying problems is shown by the fact that such problems are fully discussed by Hero of Alexandria (B.C. 285-222), several of whose works are extant. The greatest advance in survey practice made by Hero was his invention of the *diopter,* a sighting instrument for surveying purposes. The oldest instrument for measuring angles, like the cross-head which is still in use, only permitted right angles to be set out. This primitive instrument consisted of two straight-edges fastened together at right angles, a pointed vertical staff being fixed to the point of intersection. The two straight-edges were provided at each extremity with sight vanes, from which plumb-lines were suspended so as to enable the instrument to be levelled. With Hero's improved instrument, any angle could be measured. Indeed, it must be regarded as the origin of the highly perfect theodolite of the present day. It consisted essentially of a beam resting between two uprights on a pillar-like stand. The beam was movable in both directions by means of spiral screws acting on horizontal and vertical cog-wheels. It was hollowed out, and contained a metal tube, at right angles to which were glass cylinders at each end of the beam. The cylinders had special covers made of metal plate, which could be raised or lowered by means of screws. They were furnished with vertical and horizontal slits for sighting. The instrument was thus a combined theodolite and level. Two staves with sliding circular vanes were used in conjunction with it.

From the beginning of the Christian era until the Middle Ages, mining records are wanting. An ancient charter relative to the mines of the Mendip Hills is in existence. Of this Mr. Robert Hunt gives a fac-simile in his *British Mining.* It dates from the reign of Edward IV., about 1480. It is a rude attempt at plan-drawing, representing the "Myne deeps," as they were then called. At the Wieliczka salt mines, Poland, the admirable plans drawn by Martin German (1638-1648) are still preserved.

The first writer who treated mining systematically, Georgius Agricola, in his work *De re Metallica*, published in 1556, devotes an entire section (Book V.) to mine-surveying. He states, as has been frequently repeated since, that the ancient mine-surveyors strenuously endeavoured to keep their art a secret. In the Middle Ages they were in consequence superstitiously regarded as sorcerers. The divining-rod was closely associated with the practice of their profession, and in many cases that hazel-twig was trusted more implicitly than the most scientific surveying operation.

In 1686 appeared the first exhaustive treatise on mine-surveying, the *Geometria Subterranea* of Nicolaus Voigtel. This was followed by the treatises of J. F. Weidler, 1726 (in Latin); and of H. Beyer, 1749, and von Oppel, 1749 (in German). These works, by advocating the plotting of mine-surveys by means of rectangular co-ordinates, lifted mine-surveying to a higher plane.

In Great Britain, instructions for making mine surveys were published by Thomas Houghton in 1681 for the Derbyshire miners, by William Pryce in 1778 for the Cornish miners, and by Thomas Fenwick in 1804 for the Newcastle colliers.*

Importance of Mine-Surveying.—When the enormous value of mineral resources is considered, the high importance, from a commercial point of view, of the art of mining is apparent. In the United Kingdom alone, the annual value of minerals raised has approached £136,000,000, the result of the labours of some 908,000 persons directly employed in their extraction. It thus becomes a matter of the utmost importance that the extent and character of the mineral deposits should be made known. This can only be effected by careful and accurate surveys.

Mine-surveying, unfortunately, has not kept pace with the advances made in other branches of surveying; for it is to be regretted that, in many cases, mine-surveys are still made with instruments which have long been set aside as too inaccurate for surveys aboveground, although the latter rarely present such serious difficulties as are encountered underground. This is, in part, due to the conservatism of miners, a conservatism which has frequently led them to regard with contempt every kind of knowledge except that learned underground. The untrained mind treasures every truth as a mystery to be carefully guarded for individual use only. Experience has often stored an individual mind with valuable facts, which are rarely recorded. The miner trusts to his memory, and, when he dies, the results of his experience die with him. The son has to begin where the father began, and this is repeated from generation to generation, so that there has been no advance. These remarks apply more particularly to the miners of the county of Cornwall, where the mining proverb, "Where it is, there it is," still holds its own.

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* The history of mine-surveying is fully dealt with by D. D. Scott, *Trans. Inst. M.E.*, vol. xxiii., 1902, p. 575; vol. xxviii., 1905, p. 624.

Happily, a better system is beginning to prevail. Coal-mining is now carried on with a high degree of skill. Colliery managers, who formerly were generally ignorant of the theoretical principles upon which practice is based, are now submitted to a severe educational test before a certificate of competency is granted. It is, however, to be regretted that a similar examination has not been instituted for the agents of metalliferous mines. The mining schools which have been founded in various districts offer suitable opportunities for the necessary theoretical training, as also do the local classes held under the Board of Education, and under the City and Guilds of London Technical Institution.

Another cause which has retarded the progress of mine-surveying is the uncertain and speculative nature of mining. Casual failures, caused by the want of easily accessible information, frequently lead to the abandonment of highly promising mines. Mining, though speculative, is not entirely the work of chance; and he who, avoiding vague and unsatisfactory speculations, constantly stores up facts, and can grasp the extent and object of mining works, is frequently enabled to avoid expenses, in which those who are without such data would soon be involved.

In this connection, Sir Warington Smyth, in a lecture on mining, says: "At the present time, few large collieries or metalliferous mines are conducted without the aid of a satisfactory plan, but there are very numerous mines in which this department is much neglected. Moreover, there is generally a want of uniformity in system, an absence of details which should give all the information that can be laid down on paper, a deficiency of surface-objects by which the workings can at a future day be referred to their proper position, and (what may sometimes lead to the most fatal errors) a neglect of observation or notice of the variation of the magnetic-needle, according to which mining plans are almost invariably constructed. It is too often the case when mines are worked by companies, that the shareholders are so regardless of what does not, as they conceive, lead to immediate gain, that they grudge the moderate sums needful for the employment of properly qualified surveyors, and either wink at the total neglect of plans, or leave them to be carried out by men already sufficiently tasked or incapable, although they may dial with accuracy, of representing on paper what they have measured."

With reference to the foregoing remarks, as far as coal-mines and mines of stratified minerals generally are concerned in this country, the Coal Mines Act of 1911 should tend to a great improvement in the keeping up of mine-plans and in mine-surveying generally. The Act details the information which must be given on plans, and provides that they must be prepared by, or under the supervision of, a qualified surveyor, and examinations for colliery surveyors are now held simultaneously with those for colliery managers.

Moreover, at the present time, the Mining Board for Examinations, which controls the examinations for certificates of competency for both colliery managers and surveyors, will not recognise the time spent in surveying by candidates for managers' certificates as being part of the practical experience required.

Formerly it was a very common thing for a man training as a colliery manager to take up a position as a colliery surveyor (very often at a bare living wage) merely for the sake of filling in part of the five years' experience required by previous legislation. The result of this was that the making and maintenance of the plans were often entrusted to persons who had at the most only a transitory interest in the work.

For several years past mine surveyors themselves have recognised that there has been ample room for improvement in their status, and as the combined result of movements instituted in several districts, a new branch of the Surveyors' Institute has been formed, so that duly qualified mine surveyors can become members of the Institute. This, together with the Home Office certificate of competency, should go far towards raising the status of this branch of the mining profession.

As an example of an error involving great loss, serious danger, and future grave embarrassments, it may be mentioned that, according to Mr. P. W. Stuart-Menteath, at an important mine in Spain an incorrect survey caused an error of 65 metres to be made in driving a main tunnel less than 200 metres in length. In collieries, too, examples are not wanting. Thus, in 1906, at Caradog Vale Colliery in Glamorganshire, there was an inundation owing to some old workings. Trusting the old plans, which showed a barrier 22 yards away, the men worked into the old headings with disastrous results. Another case is recorded by

Mr. J. Dickinson in 1878, when an inundation occurred by which two lives were lost, from a former working being cut into without any bore-holes in advance. In this instance, there was a correct plan of the former work, but by a mistake of the surveyor, a wrong direction was set out.

Mineral Deposits.—For practical purposes mineral deposits may be divided into *tabular deposits*, including mineral veins, beds, and seams, and *irregular deposits*, including masses, stock-works, and pockets. Tabular deposits are those in which two dimensions predominate. The third smaller dimension, the perpendicular distance between the two bounding planes, is termed the thickness. The adjacent rock on both sides of these two planes is termed the *country*, the portion on which the deposit lies is the *foot-wall*, and that covering the deposit is the *hanging-wall*. With beds and seams, these are known as the *floor* and *roof* respectively. The *strike* or *course* of a deposit is the angle formed with the meridian by the direction of a horizontal line drawn in the middle plane. Its full *dip* is the inclination downwards measured in degrees from the horizontal in a direction at right angles to the strike. As the dip of veins is usually great, it is sometimes measured from the vertical, and is then termed *underlie* or *hade*. It has been proposed to use the term *pitch* to indicate the extent of the obliquity of the axis of an ore-shoot to the plane of maximum dip of a metalliferous vein, and also in connection with the obliquity of lenticular ore-bodies.* The portion of a mineral deposit occurring at the surface is known as the *outcrop*, *basset*, or (U.S.) *apex*.

Mineral veins or lodes are defined by Sir C. Le Neve Foster as tabular deposits of mineral, which have been formed subsequently to the rocks by which they are surrounded. Usually, they occupy fissures in the earth, frequently cutting across the planes of stratification of the rocks. They may occur in eruptive or in sedimentary rocks. Their contents vary, some parts containing worthless vein-matter or *gangue*, others being filled with ore. The productive portions are termed shoots or courses of ore, bunches, or ore-bodies. Cross courses are veins coursing nearly at right angles to the chief lodes of any particular mining district,

The characteristic feature of beds and seams is, that they are members of a series of stratified rocks. They may be interstratified deposits, or superficial ones, such as peat, bog iron ore, gold placers, and tin stream-works. As stratified deposits, they were originally deposited in a more or less horizontal form. The minerals occurring principally in bedded deposits are coal, anthracite, lignite, iron ore, cupriferous-shale, lead-bearing sandstone, gravels containing diamonds, or gold, or tin, sulphur, salt, clays, limestone, gypsum, oil-shale, alum-shale, and slate. Miners often erroneously speak of "veins" of coal or ironstone, when, geologically, they may be true "beds" or seams.

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* *Trans. Inst. M.E.*, vol. xxxiv., p. 236.

"Masses" are deposits of mineral of irregular shape, which cannot be recognised as beds or as veins. Such, for instance, are the red hæmatite deposits of Ulverston, the brown hæmatite of the Forest of Dean, the iron ore deposits of Missouri, the iron mountains of Gellivare and Taberg in Sweden, and the pipes of diamond-bearing rock in South Africa. They may be filled-in cavities or metamorphic deposits, such as the zinc ore deposit of Altenberg, which is 260 yards long and 65 yards broad and deep. When the whole rock is permeated with mineral matter, accumulated in minute veins, the deposit is termed a *stockwork.* Examples of such deposits occur at Carclaze and other places in Cornwall, and at Altenberg in Saxony.

No classification of mineral deposits can be quite satisfactory in all cases. A bed, for instance, even of coal may be so folded and contorted as to lose its original tabular form, and to assume the shape of an irregular mass.

Mining Terms.—Many local as well as technical terms are used in mining. The following are definitions of some of the objects most frequently named on mine-plans:—A *shaft* is a pit sunk down from the surface. In the mining of stratified deposits, the shafts sunk are usually perpendicular. In vein-mining, they may be sunk perpendicularly to cut the vein, or they may follow its underlie. *Levels* are horizontal excavations along the course of a vein, or horizontal passages, by which access is gained to the workings of the mine. A level driven from the surface, to draw off the water, is termed an *adit level,* or (U.S.) a *tunnel.* A drift or gallery driven across the usual direction of the veins generally for the purpose of searching for a new vein, or of connecting two known veins, is termed a *cross-cut.* The extreme end of any level or cross-cut is called the *forebreast* or end. A *stope* is the working from which the ore is extracted. Above a level, the working is an "overhand" or back stope; an "underhand" stope is the working downwards from the floor of the level. A *winze* is a shaft which connects two or more levels, but does not come to the surface. A *rise* is an upright winze commenced from a level and driven upwards. Surface workings include open cuts, pits, and excavations of limited extent. A tract of land let for mining purposes is known as a *sett*, *royalty*, *concession*, or *claim*.

In coal-mining, and the working of stratified deposits generally, the pair of galleries driven from the shaft are variously known as *drifts*, *headings*, *levels*, *way-gates*, *gate-roads*, and *rolley-ways*. The winning of the mineral is effected in different ways, following a variety of modifications between the two extremes—namely, the "*post and stall*" system, otherwise known as the "*bord and pillar*," or in Scotland as "*stoup and room*," and the "*longwall*" system. In the former a given district is at first formed into pillars by narrow excavations, the pillars being removed in a second operation; in the latter, the whole of the available mineral is removed in one operation, and the roof allowed to fall in.

Methods of Surveying.—The methods adopted in mine-surveying are all comprised in the term *plane-surveying*, which is applied to surveying in which all measurements are made or computed to a horizontal plane, no account being taken of the effect of the curvature of the earth, as the error so caused is quite negligible in the case of areas up to, say, 100 square miles in extent. It must be borne in mind, however, that, whilst no appreciable error is caused by considering any area of the earth's surface, up to the above limit, as a plane surface, the effect of local deviations, such as hills and valleys, cannot be ignored, and all linear measurements taken on a slope must be made in such a way that their distances as projected on a horizontal plane are obtained or can be computed.

In the case of levelling, the effect of the curvature of the earth is appreciable within comparatively short distances, but, as will be explained when dealing with this subject, the methods adopted obviate any errors due to this cause.

Plane-surveying comprises three distinct methods, *chain-surveying*, *triangulation*, and *traverse-surveying*.

Chain-surveying is carried out by means of a chain, measuring-tape, and ranging poles, and without the aid of any instruments for measuring angles except the occasional use ot simple instruments for setting-out right angles, and the relative position of the controlling points of the area under survey is fixed by means of linear measurements alone.

In triangulation-surveying, controlling points are arranged all over the area under survey, so as to form a network of triangles. The length of one side of one triangle only is measured direct, the interior angles of each of the triangles being measured usually by means of a theodolite, the lengths of all the other sides of the triangles being computed.

In traverse-surveying, the controlling points are arranged in a series of consecutive lines, and the relative position of the points determined by measuring the length of each of the lines by means of a chain or tape, the directions of the lines with reference to the magnetic meridian being measured by means of a magnetic needle; or in cases where it is not convenient or advisable to use the magnetic meridian as a standard, some other standard may be taken, the bearings of the lines with reference to this being obtained by computation after measuring the angles between successive pairs of lines with some suitable instrument. The method of traversing is the only one available for underground surveying; its use, however, is not confined to this, as in many cases it is very convenient for surface work.

Whichever of the above methods is adopted for determining the position of the controlling points in a survey, a supplementary method, known as *off-setting*, is usually adopted for filling in detail; this will be dealt with more particularly in the chapter devoted to chain-surveying. Again, whilst each of the methods outlined may be regarded as independent, in making large comprehensive surface surveys they are very often all three employed in conjunction.

Measures of Length.—The standard measure of length in the United Kingdom is the *yard*. In addition to the yard, the following units of length are used for surveying purposes:—

The *inch*, one thirty-sixth part of the standard yard. The *foot*, one-third part of the standard yard. The *fathom* of 6 feet or 2 yards. The *chain* of 66 feet or 22 yards; divided into 4 *poles* of 5½ yards, and 100 *links* of 7·92 inches. The *statute mile* of 1,760 yards or 5,280 feet or 80 chains, divided into 8 *furlongs*.

The standard yard is the distance between two fixed points on a certain metal rod at the temperature of 62° F., and under the mean atmospheric pressure. The British and United States standards are identical.

To obviate the inconveniences of the innumerable units of length used in different countries, attempts were made towards the middle of the 17th century to introduce a natural unit, which could at any time be again determined if the standard should be lost. Two proposals were considered; one being based on the length of a pendulum vibrating seconds, the other on the magnitude of the circumference of the earth. The former suggestion was due to Huygens, who proposed to divide the length of a pendulum vibrating seconds into three parts, and to term each part a foot. This method was found impracticable, since the length of the seconds-pendulum varies with the latitude at different places; thus, at London it is 39·1393 inches, whilst at New York it is 39·1017 inches.

The second plan was therefore adopted—that is, a fraction of the earth's meridian was taken as the standard. For this purpose, at the time of the French Revolution, the distance from Dunkirk to Barcelona was determined. Both these places are in the same meridian as Paris. The measurement was subsequently extended to the Island of Formentera, and, from the length determined, the distance of the pole from the equator was calculated to be 5130740·74 French fathoms (toises). The ten-millionth part of this length (0·513074 toise) was termed the *metre*, and was adopted as the French unit of length. In 1799, two similar rods of platinum were constructed as standards, having that length at 0° Centigrade. The given length of the metre being thus determined, it ceased to be a natural measure. With the present improved measuring-instruments, it is possible for us to determine the circumference of the earth with greater accuracy, whilst the length of the metre is fixed. Indeed, it is now known that the metre was determined a not inconsiderable fraction too small.

The French measures of length are multiples and submultiples of the metre. The value of the latter in British measure is 3·2808693 feet, or 39·37043 inches. For mine-surveys the metre is the unit now almost exclusively used in Continental European countries. It is also employed on Government surveys in the United States.

Special units of length used for mining purposes in various countries are the following:—

	British Fathom.	Feet.
Fathom,	1·000	6·000
Metre,	0·546	3·280
Swedish Famn,	0·973	5·844
Russian Sashon,	1·166	7·000
Austrian Klafter,	1·037	6·222
Bavarian Lachter,	1·062	6·372
Württemberg Lachter,	1·096	6·576
Hanoverian Lachter,	1·050	6·300
Saxon Lachter,	1·093	6·558
Prussian Lachter,	1·144	6·864
Spanish Vara,	0·463	2·782
French Toise,	1·065	6·394

Angular Measures.—The circumference of a circle is divided into 360 parts; each part being termed a "degree." The degree is divided into 60 minutes, and the minute into 60 seconds. This is known as the sexagesimal division.

The French centesimal division of the quadrant into 100 degrees, instead of 90 degrees, is rarely used except for surveys with the tacheometer. Each centesimal degree is divided into 100 minutes, each of 100 seconds.

Trigonometrical Formulæ.—The following is a summary of the principal trigonometrical formulæ used in surveying :—

The trigonometrical functions of a given angle may be defined as the ratios to each other of the sides of a right-angled triangle possessing the given angle. Assuming that A, B, C represent the three angles of a right-angled triangle, C being the right angle, and that a, b, c represent the sides respectively opposite to these angles, c being the hypothenuse; then the trigonometrical functions of the angle A are—

$$\sin A = \frac{a}{c}; \quad \operatorname{cosec} A = \frac{c}{a}$$

$$\cos A = \frac{b}{c}; \quad \sec A = \frac{c}{b}$$

$$\tan A = \frac{a}{b}; \quad \operatorname{cotan} A = \frac{b}{a}$$

The following equations give the most important relations amongst the trigonometrical functions of the angle A :—

$$\sin A = \frac{1}{\operatorname{cosec} A} = \sqrt{1 - \cos^2 A} = \frac{\tan A}{\sec A}$$

$$\cos A = \frac{1}{\sec A} = \sqrt{1 - \sin^2 A} = \frac{\operatorname{cotan} A}{\operatorname{cosec} A}$$

$$\tan A = \frac{1}{\operatorname{cotan} A} = \sqrt{\sec^2 A - 1} = \frac{\sin A}{\cos A}$$

$$\operatorname{cosec} A = \frac{1}{\sin A} = \sqrt{1 + \operatorname{cotan}^2 A} = \frac{\sec A}{\tan A}$$

$$\sec A = \frac{1}{\cos A} = \sqrt{1 + \tan^2 A} = \frac{\operatorname{cosec} A}{\operatorname{cotan} A}$$

$$\operatorname{cotan} A = \frac{1}{\tan A} = \sqrt{\operatorname{cosec}^2 A - 1} = \frac{\cos A}{\sin A}$$

The complement of an angle is that angle which must be added to it to make a right angle, and

$$\sin(90^\circ - A) = \cos A; \qquad \operatorname{cosec}(90^\circ - A) = \sec A$$
$$\cos(90^\circ - A) = \sin A; \qquad \sec(90^\circ - A) = \operatorname{cosec} A$$
$$\tan(90^\circ - A) = \operatorname{cotan} A; \qquad \operatorname{cotan}(90^\circ - A) = \tan A$$

The supplement of an angle is that angle which must be added to it to make two right angles. Compared with the trigonometrical functions of the angle A, those of its supplement are—

$$\sin(180^\circ - A) = \sin A; \qquad \operatorname{cosec}(180^\circ - A) = \operatorname{cosec} A$$
$$\cos(180^\circ - A) = -\cos A; \qquad \sec(180^\circ - A) = -\sec A$$
$$\tan(180^\circ - A) = -\tan A; \qquad \operatorname{cotan}(180^\circ - A) = -\operatorname{cotan} A$$

The explement of an angle is that angle which must be added in order to make 360°.

The formulæ for the solution of plane triangles are deduced from the principles that the sum of the three angles of a plane triangle is equal to two right angles, and that the sides of the triangle are proportional to the sines of the opposite angles. For right-angled triangles the most useful formulæ are :—

$$b = a \sin B \qquad c = a \cos B$$
$$b = c \tan B \qquad c = b \tan C$$
$$b = c \operatorname{cotan} C \qquad c = b \operatorname{cotan} B$$

For oblique-angled-triangles, the most useful formulæ are—

$$b = \frac{a \sin B}{\sin A} \qquad c = \frac{a \sin C}{\sin A}$$

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

CHAPTER II.

THE MEASUREMENT OF DISTANCES.

Methods of Measuring.—The straight lines which have to be measured by the mine-surveyor may be horizontal, vertical, or inclined. The measurement of horizontal lines is of the most frequent occurrence. When a line inclined towards the horizon has to be measured, the operation is, as a rule, performed with the object of determining the horizontal and vertical projections of the line. It is then necessary, in each case, to determine the angle of inclination formed by the measured line and the horizon.

Lines are usually measured with chains, tapes, or rods, divided into fathoms, yards, links, feet, or some other unit of measurement.

The Chain.—The instrument most frequently used in surveying is the chain. In coal-mines and in field-surveying in this country Gunter's chain is employed. It is 66 feet in length; 80 chains being equal to 1 mile. This length was chosen by the inventor, Edmund Gunter, in 1620, with the object of facilitating the computation of areas; 10 square chains being equal to 1 acre. The chain is composed of 100 links of iron or steel wire, each bent at the end into a ring, and connected with the ring at the end of the next piece by means of three rings. The chain is thus made more flexible and not so liable to become twisted or *kinked*. A couple of swivels are also inserted in the chain, so that it may turn round without twisting. Every tenth link is marked by a piece of brass with one, two, three, or four points, corresponding to the number of tens that the brass represents, counting from the nearest end of the chain. The middle, or fiftieth, link is marked by a brass circle. A swivel-handle is provided at each end of the chain. The wire used in the construction of iron chains is usually No. 8 S.W.G.; that used for steel chains is either No. 12, or No. 8 S.W.G.

The hundredth part of the chain is called **a** ***link***, and is equal to 0·66 foot or 7·92 inches. All calculations with chains and links can thus be easily performed by means of decimals. The following table will be found useful for converting chains into feet and feet into links :—

CHAINS INTO FEET.		FEET INTO LINKS.	
Chains.	Feet.	Feet.	Links.
0·01	0·66	1·00	1·515
0·02	1·32	2·00	3·030
0·03	1·98	3·00	4·545
0·04	2·64	4·00	6·060
0·05	3·30	5·00	7·575
0·06	3·96	6·00	9·090
0·07	4·62	7·00	10·606
0·08	5·28	8·00	12·121
0·09	5·94	9·00	13·636

For colliery use, the chain is sometimes made entirely of brass, or with ten links in brass at each end, in order to prevent the compass-needle being attracted.

It must be remembered that any error in the length of the chain will cause erroneous measurement throughout the entire survey. It should, therefore, be tested and adjusted before the commencement and at the end of every extensive survey. This is best done by having a standard marked on a level pathway or on the top of a wall, showing not only the accurate length of the chain, but also the length of every ten links. Standard 66-feet and 100-feet chains have been fixed by the Government in Trafalgar Square and Guildhall, for the use of surveyors in London.* If on testing a chain it is found to have lengthened appreciably (say over half an inch), it can be corrected by holding each link in turn very firmly in a vice and then tapping so that each junction is made to close slightly. If a line has been measured with an incorrect chain, the true length of the line may be found from the proportion :—As the length of the standard given by the incorrect chain is to the true length of the standard, so is the length of the line given by the measurement to its true length.

Accompanying the chains are ten *arrows* or iron pins, which are used in succession to mark the end of the chain in measuring a line. They are a foot long, and are made of stout iron wire sharpened at one end and bent into a ring at the other. A piece of red tape is usually attached to the rings to render the arrows visible from a distance. The chain is folded by taking it by the 50-link mark, and folding the two ends simultaneously, taking care so to cross the links that the body of the chain when folded may be smaller in the middle than at the ends. The chain is opened by taking both handles in one hand, and throwing the chain out with the other.

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* Professor H. Louis, *Trans. Inst. M.E.*, vol. xxiii., 1902, p. 85, draws attention to the various precautions that should be observed in setting out such a standard length, and details those he employed in laying down standards of 66 feet and 100 feet at the Durham College of Science.

The chain is used by two persons, the *leader* and the *follower*. The former having been supplied with the ten arrows, stretches the chain in the required direction, while the follower holds one end of it at the starting point. An arrow is then driven perpendicularly into the ground by the leader at the point where the chain ends. He then goes forward, drawing the chain after him, and repeats the same operation throughout the length of the line; the arrow last put down serving as the mark to which the follower has to bring his end of the chain. The arrows are taken up by the follower as he advances, until he has them all, when they are returned to the leader to be used over again. The arrows are thus changed from one to the other at every 10 chains' length; care being taken to note each change in the field-book. At the end of the line, the number of changes added to the number of arrows in the follower's hand, and to the number of links extending from the last arrow to the end of the line, gives the total length of the line measured. If the ground is so hard that an arrow cannot be driven in, the leader marks the ground and lays the arrow down. Eleven arrows are sometimes preferred. The eleventh is used to mark the end of the eleventh chain; another being substituted for it before the leader goes on. During the operation, the follower has to see that the chain is tight, straight, and unentangled, and to direct the leader so as to enable him to place the arrow in the ground exactly in the alignment.

In measuring lines in a colliery, the arrows are usually dispensed with; the end of each chain being marked with a piece of chalk.

The chain used in metalliferous mines is 10 fathoms or 60 feet in length, and is provided with brass marks at every fathom. Each link of the chain is 6 inches in length. The chain is sometimes made entirely of brass. No advantage is gained by using Gunter's chain in a metalliferous mine, since acreage has never to be calculated, and measurements have to be made with such precision that the inch is to be preferred to the link as a unit.

Chaining on Slopes.—In chaining up or down a slope, the distance must be reduced on the plan to the projection of that distance on a horizontal plane. If the slope is gentle, the lower end of the chain may be raised until the chain is level. To ensure the raised end being exactly above the right spot, the chain may be raised along a vertical staff, or an arrow may be carefully dropped, or, better still, a plumb-line may be employed.

Angle. Degrees.	Slope.	Gunter's Chain. Correction in Links.	10-fathom Chain. Correction in Feet.	100-foot Chain. Correction in Feet.
3	1 in 19·08	0·14	0·08	0·14
4	1 in 14·30	0·24	0·14	0·24
5	1 in 11·43	0·38	0·22	0·38
6	1 in 9·51	0·54	0·32	0·54
7	1 in 8·14	0·74	0·44	0·74
8	1 in 7·11	0·97	0·58	0·97
9	1 in 6·31	1·23	0·73	1·23
10	1 in 5·67	1·52	0·91	1·52
11	1 in 5·14	1·83	1·09	1·83
12	1 in 4·70	2·18	1·30	2·18
13	1 in 4·33	2·56	1·53	2·56
14	1 in 4·01	2·97	1·79	2·97
15	1 in 3·73	3·40	2·04	3·40
16	1 in 3·48	3·87	2·32	3·87
17	1 in 3·27	4·37	2·62	4·37
18	1 in 3·07	4·89	2·93	4·89
19	1 in 2·90	5·44	3·26	5·44
20	1 in 2·74	6·03	3·61	6·03
25	1 in 2·14	9·37	5·62	9·37
30	1 in 1·73	13·39	8·03	13·39

The rate of slope (the ratio of the hypothenuse to the prependicular) is the cosecant of the angle of inclination. The rate of inclination (the ratio of the base to the perpendicular) is the cotangent of the angle of inclination.

The process is called *stepping*, and, on steep ground, may be carried on by half-chains, or even shorter distances. A more accurate method is to measure the angle of the declivity. The cosine of this angle, multiplied by the measured hypothenuse, gives the length of the horizontal distance.

The most convenient method is by means of a *correction* to be deducted from each chain. This correction, being known, may be applied mechanically during the chaining by pulling the chain forward at each chain-length through a distance equal to the required correction.

The preceding table gives the correction for each chain measured on the slope.

In order to save calculation, many mining dials and theodolites have the correction for declivity marked on the graduated arc on which angles are measured.

Steel Bands.—The most suitable instrument for measuring lengths in mine-surveys is the steel band. It is more convenient and less liable to inaccuracy than the chain. It is usually 100 feet, or 100 links, in length, with feet etched on one side and links on the other. It is provided with a handle at each end, and is wound on a steel or wooden cross. It is employed in precisely the same way as the chain. Like that instrument, it presents the advantage of rapidity; but it has the additional advantage of representing a length of which the variations are dependent only on the temperature, since it does not kink, stretch, nor wear so as to change its length.

In surveying the anthracite mines of Pennsylvania, Mr. E. B. Coxe * used a measuring-tape made of a ribbon of tempered steel, 0·08 inch broad and 0·015 inch thick. It is 500 feet long, and weighs 2 lbs. 7½ ozs. At each tenth foot a small piece of brass wire is soldered across the tape, the white solder extending about an inch on each side of the wire. In the latter is filed a small notch which marks the exact spot where the tenth foot ends. The distances from the zero point of the tape are marked upon the solder by counter-sunk figures. The white solder enables the 10-feet notches to be found very easily, and the counter-sunk figures, being filled with dirt, stand out upon the white ground of solder. The tape is wound upon a simple wooden reel, 10 inches in diameter, which can be held in one hand and turned by the other. Two brass handles, which can be detached, accompany the tape, and are carried upon the reel.

The advantages of the tape are—(1) the greater facility in measuring up and down slopes, or along the face of the coal; (2) greater accuracy in measuring from one station to another, as the tape forms a straight line from one station to the other, and there is no error from the use of arrows; (3) the tape does not stretch appreciably. Its disadvantages are—(1) it is liable to break, unless carefully handled; (2) it is necessary to roll it up and unroll it again when the distances vary very much.

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* *Trans. Amer. Inst. M.E.*, vol. ii., 1874, p. 219.

The tape, however, can be easily mended when it breaks. For this purpose, a small sleeve of brass is made tinned inside, in which the broken ends of the tape are slipped and then soldered by heating the sleeve with a red-hot poker.

There are three sources of error in the use of the steel tape, (1) the extension of the tape by stretching; (2) the shortening of the tape in consequence of its assuming the form of the catenary curve; and (3) the contraction or expansion due to change of temperature. The tape does not stretch to any appreciable extent, and any error thus caused is compensated by the shortening due to the formation of the catenary curve by the tape. The true distance indicated by a 500-foot steel tape, when subjected to the usual tension of 40 lbs., is calculated to be 499·9185 feet. With regard to the expansion caused by change of temperature, a tape measuring 500 feet in length at 32° F. becomes 500·6 feet in length at 212°, so that a variation of 60° causes a variation of only 0·2 foot in a 500-foot tape.

A steel band, 300 to 700 feet long, is to be recommended for all important surface work in mine-surveying, whilst the chain should be used for filling in details, and where extreme accuracy is unnecessary.

Measurement of Base-lines in Trigonometrical Surveys.—Before compensating bars were invented, steel chains were employed for base-measurement in the Great Trigonometrical Survey of the United Kingdom. In using the steel chain, a drawing-post and a weight-post were used; a 56-lb. weight being always applied to one end of the chain, whilst the other was fixed to the drawing-post. The chain was made to rest in deal coffers supported by trestles, in order to obtain a perfectly level surface, and thermometers were placed at different distances in order to ascertain the temperature of the chain, so that the base might be reduced to its value at a given temperature. The chain was 100 feet long, and consisted of 40 links, each ½ inch square.

When very accurate measurements were required, deal rods were at one time largely used instead of the chain for measuring long lines. They were, however, soon discarded in exact operations, as experience showed that they were liable to sudden and irregular changes in length from dryness or humidity. Saturated with boiled oil, and afterwards covered with a thick coat of varnish, well-seasoned wooden rods will be found sufficiently exact for ordinary purposes. Such rods are usually made of lance wood, and are 5 feet in length. They must be placed in line very carefully end to end. They are rarely placed directly on the ground, which, as a rule, is too uneven. A horizontal line may be constructed along the base to be measured, by means of a stretched cord.

On the Trigonometrical Survey of the United Kingdom, glass rods were substituted for wood in the measurement of the Hounslow base in 1784. Their ends were protected with metal caps. The results obtained were perfectly satisfactory, measurements with the glass rods and a check measurement with a steel chain of perfect workmanship, giving results that differed by little more than half an inch in the base-line of 27,404 feet. Steel rods also have been found useful.

For the measurement of the Loch Foyle base, an apparatus was devised bv Colonel Colby. In this he obtained an unalterable linear measure by using compensating expansions. Two bars, one of iron, the other of brass, 10 feet long, were placed parallel to each other, and rivetted at the centre, it having been found by numerous experiments that they expanded or contracted in the proportion of 3 to 5. The brass bar was coated with some non-conducting substance, in order to equalise the susceptibility of the two metals to change of temperature. Across each end of these combined bars was fixed a tongue of iron, with a minute dot of platinum so situated on this tongue that, with every change of contraction or expansion, the dots at each end always remained at the constant distance of 10 feet.

The methods of base-line measurement outlined above, whilst giving great accuracy, are very tedious and costly, the modern method is to use very aocurate steel tapes, preferably made of *invar*, which is a nickel-steel alloy containing 36 per cent. of nickel, and whose contraction and expansion with varying temperature is the least of any known metal or alloy. The measurements may be made along the surface of the ground, or the tape may be supported on trestles placed at each end, the latter method enabling a more accurate result to be obtained, although the former is quite accurate enough for all mine-surveying purposes, providing a sufficient length of suitable ground is available, the probable error varying from 1 in 10,000 to 1 in 30,000. Corrections have to be applied in both cases, the chief being for temperature and tension, and in the second method correction for sag is very important. If the base-line is laid out on sloping ground, the angle of slope must be measured and the horizontal equivalent computed.*

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* For full details of base-line measurement by modern methods, see *Text-book of Topographical and Geographical Surveying*, by Colonel C. F. Close, C.M.G., R.E., second edition.

Field-Compasses.—These are rods 3 to 4 yards in length, terminated by two points, and provided in the middle with a builder's level and a handle. This apparatus is often used on the Continent for filling in details.

Measuring-Wheel.—The viameter, or measuring-wheel, is sometimes used for measuring station-lines. The wheel is rolled over the ground to be measured, and its motion is communicated to a series of toothed wheels so proportioned that the index-wheel registers their revolutions, and records the whole distance passed over. On very even ground the results are fairly satisfactory.

Pacing.—A line may be measured by pacing, with tolerable accuracy. This method consequently is frequently employed on explorations, preliminary surveys, and in levelling with the aneroid barometer. In order to obtain accurate results, the surveyor must accustom himself to an accurate pace. This may be done by pacing a distance of 200 to 300 yards repeatedly, until the same number of paces is always obtained. An instrument, called a *passometer*, made in the form of a watch may be conveniently used for registering the number of paces, thus precluding the absorbing attention required for accurately counting a considerable number of paces. The distance may be registered direct by a similar instrument, the *pedometer*, which can be adjusted with facility to long or short steps.

The usual step is the military pace of 30 inches, 108 of these paces per minute representing a velocity of 3·07 miles an hour If no unfavourable conditions come into play, for example, slope of the station-line or fatigue, a distance may be determined by pacing accurately to within 2 per cent. The pace of the surveyor should be re-measured from time to time, since after the age of 25 to 30 years, the length of the pace diminishes considerably with increasing age.

On slopes, the pace is always shorter than on level ground Professor W. Jordan gives the following averages :—

Rise.	Pace.	Fall.	Pace.
	Inches.		Inches.
0°	30·3	0°	30·3
5°	27·5	5°	29·1
10°	24·4	10°	28·3
15°	22·0	15°	27·5
20°	19·7	20°	26·3
25°	17·7	25°	23·6
30°	15·0	30°	19·7

The relation between the height of the individual and the length of his pace, may be seen from the following averages :—

Height.		Pace.	Height.		Pace.
Feet.	Inches	Inches.	Feet.	Inches.	Inches.
5	0	29·5	5	8	31·5
5	2	30·3	5	10	32·2
5	4	30·7	6	0	32·6
5	6	31·1	6	2	33·0

Accuracy of Linear Measurements.—Professor F. Lorber, of the Leoben School of Mines, has made a careful study of the accuracy of linear measurements. From 6,000 measurements, he deduces the following table showing the mean error of each method employed. The error is proportional to the square root of the length, according to the theory of probabilities. The mean error *m* in measuring a line L by six different methods is as follows :—

	Square root of L multiplied by
Two rods along a stretched cord,	$m = 0{\cdot}000535$
Two rods, without cord,	$m = 0{\cdot}000927$
Chain,	$m = 0{\cdot}003000$
Steel band,	$m = 0{\cdot}002160$
Field-compasses,	$m = 0{\cdot}002120$
Measuring-wheel,	$m = 0{\cdot}003600$

The mean error is thus approximately—

1 : 2 : 6 : 4 : 4 : 7,

according to the method employed. Thus, a measurement with rods along a stretched cord is six times as exact as a measurement of the same line with the chain. From the results given above, it is evident that measurements with rods along a stretched cord are the most exact, whilst, with the exception of the measuring-wheel, the chain gives the most untrustworthy results. The steel band, too, gives results one and a half times more accurate than those given by the chain.*

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* Improved methods of chaining are described by W. M. Thompson, *Min. Proc. Inst. C.E.*, vol. xcii., 1888, p. 268. When excessive accuracy is required, M. Przyborski, *ibid.*, vol. cxliv., 1901, p. 356, recommends hooking a spring-balance to the steel band and maintaining a constant tension. The balance is a brass tube, 4 inches long, containing a spring and a piston with an indicator working in a side groove. A small stop prevents overstretching.

Normal errors, such as those due to defects in the instrument, and errors in alignment, increase in proportion to the length. For the various instruments, with the exception of the rods along a stretched cord, where the normal error r is reduced to a minimum, these errors are as follows :—

Two rods, without cord, ... $r = -0{\cdot}00008\,L$
Chain, ... $r = +0{\cdot}00046\,L$
Steel band, ... $r = -0{\cdot}00032\,L$
Field-compasses, ... $r = -0{\cdot}00079\,L$

In the case of the chain only is the error positive; that is to say, the length measured is longer than the true length.

The rapidity of measuring is shown by the following averages :—

Instrument.	Assistants.	Mean Speed per Minute.	
		Absolute.	Per Assistant.
		Feet.	Feet.
Rods, ...	2	45	22
Chain, ...	2	59	29
Steel band, ...	2	65	32
Field-compasses, . .	1	85	85

CHAPTER III.

CHAIN-SURVEYING.

Principles.—This method of surveying depends upon the fact that the form of a triangle is fixed by the length of the sides, hence by measuring these the shape and area can be determined and a plan constructed from the measurements. The triangle is the only plane figure of which the form cannot be altered if the sides remain constant, so that when linear measurements only are used in surveying, this fact must be borne in mind.

The area to be surveyed is divided up by a system of triangles, arranged so that the external lines of the system follow approximately the course of the boundary, the exact form of which is determined from subsidiary measurements from these lines. Interior details, such as buildings, fences, roads, etc., are filled in from the interior lines of the system of triangles or from lines whose direction can be fixed from them.

Stations.—This is a term used in surveying to denote a point where two or more lines converge or intersect, thus each of the corners of the above triangles are stations, as also are the points from which lines required for filling in the interior detail are run. The lines between the stations are called station-lines or chain-lines.

Tie-Lines.—In order to ensure that the chain-lines have been correctly measured and subsequently plotted correctly, a check line or tie-line is measured for each of the triangles in the system, a line from one of the corners being usually run as perpendicularly as possible on to the chain-line opposite, the point of intersection being noted. If the distance as measured on the ground agrees with that obtained by plotting on the plan, all the measurements can be reasonably assumed to be correct.

Off-sets are the subsidiary measurements, above referred to, taken to fix the controlling points of the boundary or other features under survey, with reference to the chain-lines. They are single-line measurements taken from known points on the chain-lines.

They are usually made with a linen tape, the right angle being judged by the eye or by the simple expedient of finding the shortest distance between the point being off-setted and the chain-line. It will be evident that the accuracy with which the point is fixed depends largely on the correctness with which the right angle is judged and the length of the off-set, so that they should always be as short as circumstances will permit, and this point should be kept in mind in arranging the triangles. Off-setting is carried on simultaneously with the measurement of the chain-lines and the procedure in the case, for instance, of a boundary fence or wall is as follows :—A careful observation is made for each point where the direction of the boundary changes. The ring of the tape is held at the point, and the tape pulled out until the chain-line is reached; it is then kept fairly taut, and made to describe an arc with the ring as centre. By this means the shortest distance, which, of course, must be the required perpendicular, is obtained, and the readings of the tape and the chain are entered in the notes as the distance of the off-set and its position on the chain-line respectively. The selection of the points for off-setting an irregularly curved boundary is a matter of some judgment, the aim being always to obtain as true a representation of the form of the boundary as possible; it is decided to a certain extent by the scale to which the survey will be subsequently plotted, although it is always advisable to allow for the possibility that a larger scale plan may sometime be required. In the case of a boundary which follows a regular curve, the off-sets should be taken at equal intervals on the chain-line, say every chain or half-chain, depending on the radius of the curve. In off-setting walls the measurement is usually made to the face of the wall, and an allowance made for the thickness to the centre.

A word may be said here with reference to the delineation of boundaries. A so-called boundary wall or fence may not be the actual boundary, which may follow the course of a ditch running alongside, or may be a uniform distance of, say, a yard on one or other side of the fence or wall. Local practice with regard to such matters must be ascertained or legal evidence obtained, as in the case of valuable mineral properties it may be a matter of considerable financial importance.

The method of fixing the position of buildings can best be followed from the example of a survey given on p. 39, *et seq.* (see Lines, 23, 24, pp. 52, 53).

Oblique Off-sets.—Where it is desired to fix the position of a point with greater accuracy than can be attained by a simple off-set, what are known as oblique off-sets may be taken. In this case measurements are made from two points separated by a convenient distance on the chain-line to the point whose position is to be fixed, forming with the distance on the chain-line a small subsidiary triangle.

Reconnaisance.—In applying the method of chain-surveying to extensive areas, the first procedure should be to make a very careful reconnaisance of the whole of the ground, during which sketches should be made giving a fairly good idea of the form of the boundary and the approximate position of the principal features which have to be incorporated. The arrangement of the lines can then be made in such a way that well-conditioned triangles are obtained and obstacles to chaining and difficult ground avoided as far as possible. In carrying out a reconnaisance full advantage should be taken of any existing plans or maps that may be available. After the reconnaisance has been completed a diagrammatic sketch is made showing the arrangement of the principal lines.

Ranging.—This is the operation of laying out the lines on the ground, and is carried out with the aid of ranging rods or poles, which are usually made of wood, and are about 6 feet in length, tapering slightly from the bottom, which is shod with iron and pointed so that the poles can be pushed into the ground sufficiently for them to stand firm. They are painted in alternate divisions of black and white, red and white, or better still, of red, black, and white, so that they have a very distinctive appearance, which enables them to be picked out readily at a distance. The length of the painted divisions is usually made of exactly a foot or link, so that short off-sets can be measured with them.

For ranging over hilly country, poles up to 10 feet long are sometimes found useful, as with these a longer line of sight is possible. The rods which mark the position of stations may be rendered more conspicuous by the aid of flags. These should not be too large, otherwise, if there is any wind blowing, they tend to pull the pole out of the vertical. Satisfactory flags can be made by joining together two pieces of red and white bunting to form a rectangle about 14 × 7 inches, one of the shorter sides being folded over and sewn to form a sleeve, closed at the top, to slip over the poles, the flag being secured by means of a tape sewn to the lower end of the sleeve. Triangular-shaped flags, though rather more troublesome to make, are quite as efficient, and have less tendency to pull the poles over.

In carrying out the operation of ranging, a pole is put in at the starting point of a line, as decided by the scheme already arranged. The surveyor then stands behind this and directs his assistant to walk in a line in the approximate direction desired, and put in a second pole at a convenient distance. When these two poles are set up the absolute direction of the line is considered as being fixed, and must be maintained until the whole line is laid out. The line is extended by the assistant taking a third pole and walking on to about an equal distance and fixing this so that it is exactly in line with the other two. In order to make the alignment correctly, the observer stands with his face quite close to the pole, which should be between his eyes, and adjusts his position until the two distant poles appear coincident.

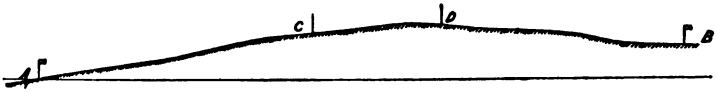

Fig. 1.

The accuracy of the alignment depends mainly on the verticality of the poles and the distance between them. The latter is decided by the clearness of the atmosphere and the flatness or otherwise of the ground, and should be made as long as possible with the proviso that there shall be no effort required on the part of the chainmen to see from rod to rod. As the chaining proceeds the back rods are collected for use on the forward part of the line.

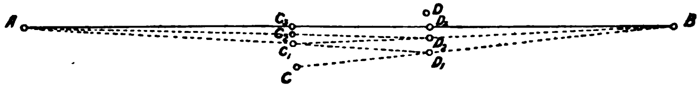

Fig. 2.

In the above description it has been assumed that the general direction of the line could be given from the starting point. Where the profile of the ground renders this impossible, the procedure has to be varied. Two typical cases will now be considered. First, taking a case as represented by Figs. 1 and 2, the former showing a section along a line which has to range between the two points A and B, and the latter the position in plan. As will be seen from the section, the two points are invisible from one another, but both visible from the two intermediate points C and D, situated at the summit of the hill, these points being selected as nearly as can be judged in the direction of the line, and as far apart as possible. Poles provided with flags are inserted at A and B, and an observer with a pole at each of the points C and D. Starting at C, say, the observer directs the one at D into the line CD_1B. The observer at D_1 then directs the one at C into the line D_1C_1A. The operations are repeated until the poles originally at C and D are simultaneously in line with one another and A and B respectively, when they must occupy the positions indicated by C_3 and D_3 on the line AB.

Take a second case, where the ends of the line are separated by high ground, and it is impossible to obtain two intermediate points, from which both ends of the line can be seen. The only method of ranging is by trial and error. Starting from one end of the line, the first two poles are set up as nearly as can be judged in the required direction, and the line so formed is extended by the ordinary method of ranging until it is past the point where the required line ends. As the ranging is proceeding the full approximate distance is measured by pacing or rough chaining, the distance between the first two poles being noted; the lateral deviation at the end of the line is ascertained by off-setting from the desired finishing point on to the trial line, the proportionate deviation for the distance between the first two poles is calculated, and the direction corrected accordingly, and the second trial line is then ranged. It may be necessary to repeat the operations if the line has to be run between two points definitely fixed, but this can usually be avoided by suitably arranging the order in which the lines are to be chained.

Setting Out Right Angles.—It is occasionally found necessary to set out a right angle from a point on a chain-line. This may be done by means of the chain alone, using one or other of the methods to be described. The first would be adopted when the point from which the right angle to be set off is over 30 links from either end of the chain-line, and the second would be adopted where the perpendicular is to be set off from the end of the line or within 30 links of the end, and it is not convenient to extend the line.

Fig. 3 illustrates the first method; it is desired to set off a perpendicular from the point A on the line BC. A distance of 30 links is measured off on either side of A to the points D and E. The handles of the chain are fastened to the ground at these points by means of arrows. The surveyor then takes hold of the chain at the 50-link mark, and pulls it away from the line to the side on which the perpendicular is required until the two half-chain lengths are quite straight. The 50-link mark then occupies the position F in the figure, the line AF being at right angles according to a simple geometrical proposition.

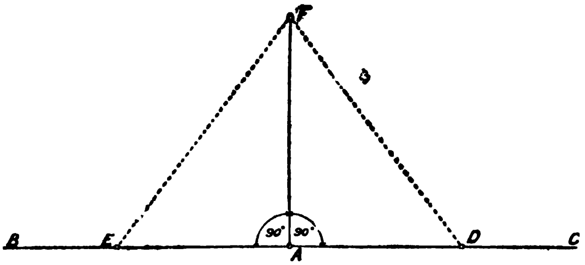

Fig. 3.

The second method is illustrated in Fig. 4, and depends upon the fact that the shorter sides of a triangle whose sides are in the proportion of 3, 4, and 5 must contain a right angle. It is desired to set off a perpendicular from the point A. A distance of 40 links is measured off along the chain-line AB to a point C, one handle of the chain is kept in position by an arrow at A, and an arrow is put through the chain at the 80-link mark, and inserted into the ground at C. Taking hold of the chain at the 30-link mark, it is pulled away from the chain-line until the two sides of the chain are straight. The 30-link mark then occupies the position D, the line AD being at right angles to AB.

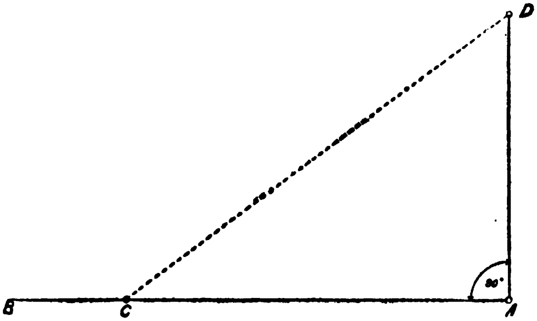

Fig. 4.

The setting out of right angles can be performed much more quickly and accurately by means of either the cross-staff or the optical square, the latter, owing to its shape and size, being a particularly convenient instrument for use in chain-surveying.

Cross Staff.—The construction of this is shown in Fig. 5. It consists of an octagonal metal box provided with two pairs of sights fixed at right angles to each other. The box is capable of being rotated about a vertical axis attached to a hollow spindle, which can be slipped over the head of a spiked rod fixed in the ground on the chain-line at the point from which the perpendicular is to be set off. The box is rotated until one pair of the sights is in line with a ranging rod on the chain-line. The surveyor then looks through the pair of sights at right angles and directs an assistant to place a pole in line with the sights. The operation is very simple, and can be quickly carried out.

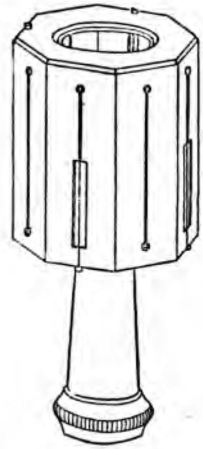

Fig. 5.

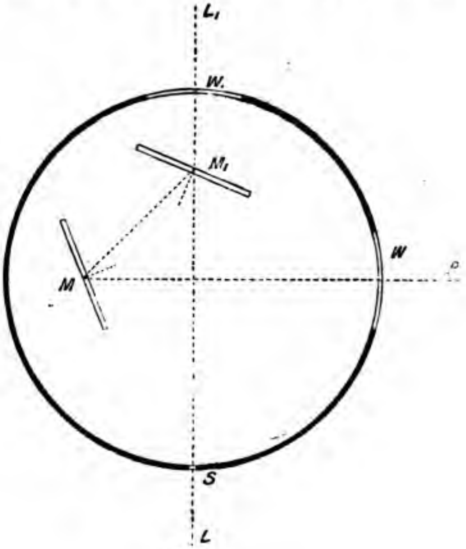

Fig. 6

Optical Square.—This instrument consists of a flat circular box containing two mirrors set at an angle of 45°, a sighting aperture and two windows being arranged as indicated in the diagrammatic sketch (Fig. 6). The instrument depends for its action on the optical law that the final direction of a ray of light after reflection from the surface of two mirrors set at an angle, makes an angle with the original direction equal to twice the angle between the mirrors. In the figure the two mirrors are shown at M and M_1, the upper portion of the mirror at M_1 being left unsilvered, so that an object can be viewed direct from the sighting aperture S through the window W_1.

In use the instrument is held in the hand at the position at which the perpendicular is to be erected, on the chain-line, the direction of which is indicated by the dotted line LL_1; a pole fixed at some distance away on the chain-line is sighted direct, and an assistant provided with a pole is directed to move until the doubly-reflected image of his pole appears as a continuation of the pole fixed on the chain-line, the assistant's pole being then in the line MR at right angles to the chain-line.

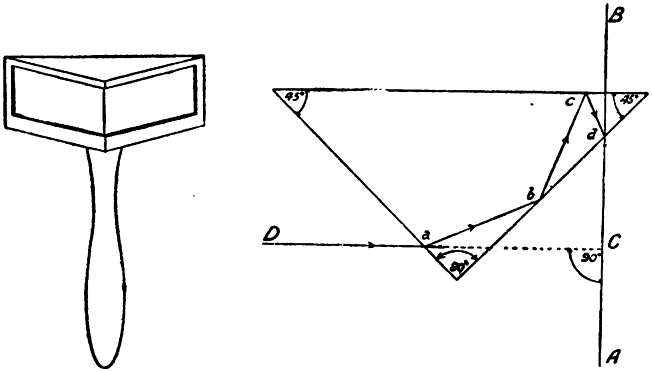

Fig. 7.

The instrument is about 2 inches in diameter, and can be comfortably carried in a waistcoat pocket.

The principle of the optical square is also applied in another instrument for setting out right angles, which has recently been fairly extensively used, and which may be termed the *prismatic square*. It is illustrated in Fig. 7, the left-hand sketch showing the general appearance of the instrument, being about two-thirds the natural size. It consists of a solid glass prism, with the faces ground accurately to the angles shown in the right-hand part of Fig. 7. The face opposite the right angle is silvered, the other faces being left plain. In setting off a perpendicular, the observer holds the instrument in his hand above the point on the chain-line, and looking above the top of the prism, sights a pole fixed at a convenient distance away on the line. An assistant is directed to fix a pole in such a position that its image, viewed through the prism, appears as the continuation of the pole viewed direct. The line between the second pole and the instrument is then at right angles to the chain-line, as will be evident from the above figure, in which AB represents the chain-line, C the point at which the perpendicular is to be erected, the path of a ray of light from the second pole at D following the direction D*abcd*A.

This instrument possesses an advantage over the optical square in that the reflecting surfaces cannot get out of adjustment.

Obstacles to Measurement.—In measuring chain-lines various obstacles are occasionally encountered, which prevent the chaining being carried out in the ordinary manner at the points where they occur. Such obstacles should be avoided as far as possible, this being one of the principal objects of the preliminary reconnaissance. It is not, however, always possible or convenient to avoid them, and one or two typical cases are considered to meet such difficulties as are likely to be encountered.

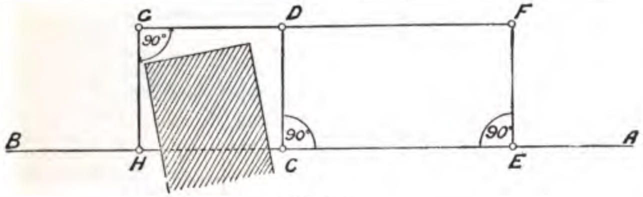

Fig. 8.

The first case taken will be one where the line cannot be ranged through, such an obstacle being presented by a building or a densely-wooded plantation, lying on low ground, the general ranging of the line up to the obstacle on either side being possible owing to the ends of the line being on higher ground. The case is illustrated in Fig. 8, in which the chaining is proceeding in the direction AB. It is continued up to the point C, where a perpendicular CD is set out to clear the obstacle, a pole being inserted at D. A distance at least equal to the width of the obstacle is measured back along the line to a point E, and the perpendicular EF set out equal in length to CD. A pole is put in at F, and the line FD, which is parallel to AB, extended to G clear of the obstacle. The perpendicular GH is set out from FG to cut the chain-line at H. The distance DG is measured and added to the chain-line measurement of C, giving the measurement to H, from which point the measurement is carried on in the ordinary manner. The points of intersection of the line with the obstacles are obtained by forward and backward measurements from C and H respectively. Off-sets may be taken from any of the lines used in the process if these are noted.

In the second case, which is illustrated in Fig. 9, an obstacle such as that presented by a water-course more than a chain-length across, is taken, this being a case more likely to arise than any other, as being more difficult to avoid.

In this case the ranging of the line is uninterrupted, and a pole is put in on the far side of the obstacle at H, the chaining, which is proceeding from A to B, is carried up to the point C, at which a perpendicular CD, about equal in length to the width of the gap, is set off, and a pole set at D. A similar distance is measured back along the chain-line to E, and a perpendicular set-off from this point on the same side as CD, and marked by two poles. The surveyor then takes another pole, and retires from the chain-line along the perpendicular set-off from E until his pole is also in line with the poles at D and H. A pole is inserted at this point, F, and the distances EF, EC, and CD are measured. From the data so obtained the width of the gap is ascertained as follows;

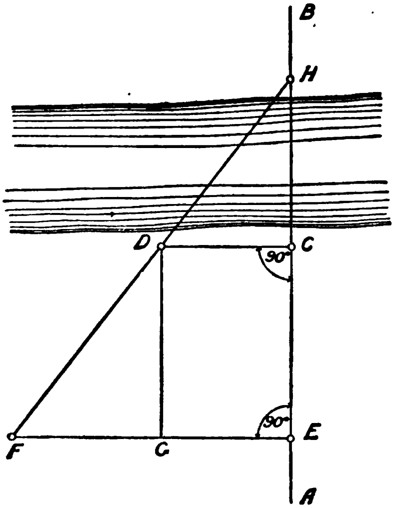

Fig. 9.

—In the figure a perpendicular DG on to EF cuts off a triangle DGF similar to HCD, in which DG = CE and GF = (EF − CD), then $CH = \frac{CD \times DG}{EF - CD}$. The measurement up to the point H is thus obtained, and chaining proceeded with in the ordinary way

Another method of applying similar triangles is shown in Fig. 10, where the obstacle is of a similar character to that shown in the last case. A perpendicular is set off from the chain-line AB at D, the distance DF being made about equal to the width of the gap. At F a perpendicular to EF is set off, and its intersection with the chain-line at C marked by a pole. FD and DC are then measured. The triangles EDF and FDC being similar, $ED = \frac{DF^2}{DC}$.

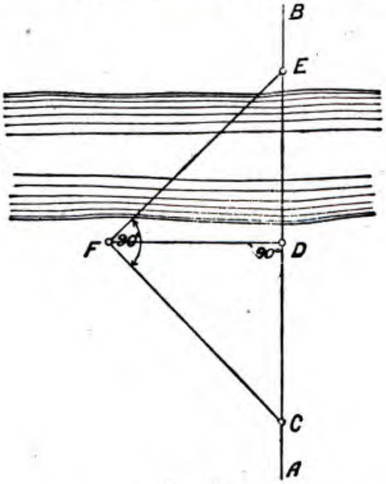

Fig. 10.

Many more methods of estimating gaps in chain-lines are available, most of them being based on the solution of similar triangles, and many are equally as suitable as the ones considered. The chief point to remember in their practical application is that the triangles should be so arranged that in the estimation of the distance required, multiplication of errors in the measurements actually made is avoided.

Field Book.—This term is applied to the notes of any survey, whether surface or underground, taken at the time the survey is being made. The recording of the notes is a matter of the highest importance, and considerable practice and unremitting care are necessary in order to produce a field book which can readily be plotted by an independent draughtsman, whose sole guide is the field book itself.

The method of entering the notes varies considerably, the most usual form being that adopted for the example ot a chain survey shown on p. 39, *et seq.* In this a double line is ruled up the middle of the page to represent the imaginary chain-line broadened out. Many surveyors prefer to represent the chain-line by a single line in place of a double one; the adoption of one or the other is a matter of individual taste.

The entry of the notes starts at the bottom of the page and proceeds upwards, and whilst in the act of entering the notes the surveyor should always stand so as to be looking in the direction in which chaining is proceeding, so that it comes natural to make the entries in their correct relative positions. Ample space should be allowed between the entries on the chain-line, crowding of the notes almost inevitably leading to confusion. In the example given, the bookings might with advantage occupy considerably more space, which has, however, here been minimised in order to meet the exigencies of publication.

The book itself should be made up with good quality paper, and the binding should be flexible, so that the book can be opened out quite flat without fear of loosening the leaves. It facilitates reference if each of the pages is numbered. The pencil used for entering notes should be of good quality, and should be soft enough to make a perfectly legible entry, yet one which will not be affected by fairly hard friction. The grade H or HB of most good makes will usually be found satisfactory.

At the commencement of the field book the title of the area under survey should be stated, together with the names of the surveyor and his assistant, and the date. The number of the line then follows, its starting point being indicated. Distances on the chain-line are entered between the ruled lines; off-sets are noted by simply entering their lengths opposite the entry on the chain-line to which they refer. The position of stations is denoted by a dot surrounded by a circle, or by underlining their chain-line measurement. Oblique off-sets are indicated by dotted lines (see line 5 at 149 and 237 in the example of the field book). In entering the measurements necessary for showing buildings it will often be found advisable to make a supplementary enlarged sketch. In sketching in details no attempt should be made to draw to scale; it is rather more to the purpose to exaggerate certain features, and to make all entries in such a way that they are capable of one interpretation only. The same conventional signs for distinguishing various kinds of fences, walls, etc., that are used for plans should also be used for the field book.

In the example of the field book shown, the approximate bearings of some of the main lines are given; this is done in order to avoid ambiguity, otherwise no indication would be given as to which side, for example, of line 1, lines 2 and 3, should be plotted. These bearings, it should be borne in mind, are only approximate, and given only for the purpose indicated.

The finishing station of each line is indicated in a similar manner to the starting station.

The diagram of lines should be made up as the survey is proceeding, and will be found of the greatest assistance in plotting the survey.

Carrying Out of Extensive Surveys.—The survey of a big estate which forms the royalty of a mine is usually a fairly expensive and lengthy operation. Accuracy of results should always be the first consideration, but the question of expense has also to be considered, and it is generally found that the cost is reduced to the lowest possible amount by making such arrangements that the work can be carried out expeditiously and, as far as possible, without interruption.

Personnel.—The party should consist of the surveyor and three assistants, two of whom, if not already experienced, can quickly be taught to chain and take off-sets. The third assistant will be found useful for bringing up back poles and for a number of incidental duties. A code of signals should be arranged, so that the surveyor can give simple instructions from a distance.

Equipment.—The following equipment should be provided, and, as will be seen, allowance is made for possible breakage or loss, so that the work shall not be unduly impeded:—Two steel chains and sets of arrows, light chains (12 B.W.G.) being preferable except for rough ground, when heavier chains (8 B.W.G.) should be used. The arrows should all have pieces of red braid attached, so that they can readily be discerned. A 100-foot steel band for testing chains from time to time. Two linen tapes, 66 feet long, for off-setting. A dozen 6-foot ranging poles; for hilly ground half the number should be about 9 feet long. A number of wooden pegs 1 inch square in section and about 4 inches long, and pointed at one end; these are for marking stations, and a stock of a few dozen should be kept available. A mallet or hammer for driving in pegs. The foregoing represent the really indispensable articles of equipment. The following will be found to be very useful adjuncts:—A pair of good field-glasses, an optical square or prismatic square, and a simple though well-constructed pocket compass.

Example of Chain Survey.—The following diagram of lines and field book for a survey intended for the production of a plan on a scale of two chains to the inch are given, together with a small scale plan, to illustrate the method of carrying out a chain survey.

In this case the reconnaissance reveals only one source of trouble—viz., the rather thickly-wooded plantation, which presents considerable difficulty in ranging and chaining, the ground generally being fairly flat. Had the plantation been non-existent, following the usual practice of basing the scheme on the longest line available, a line would have been run from the south-west corner to the north-east corner, and all the main triangles established on this. Under the circumstances the arrangement adopted was considered advisable, though it will be seen that several modifications are possible.

Attention should also be called to the fact that two of the principal stations are outside the boundary of the area, and necessitate permission from the occupiers of adjoining land to allow access to them. It is always preferable to arrange the lines so that they are within the boundary of the property, but if operations can be facilitated by such an arrangement, as shown in the example, no hesitation should be made in applying for the necessary permission, especially as it is very rarely withheld.

Plotting of Chain Surveys.—The methods employed in plotting the notes of chain surveys is dealt with in Chapter XIII.

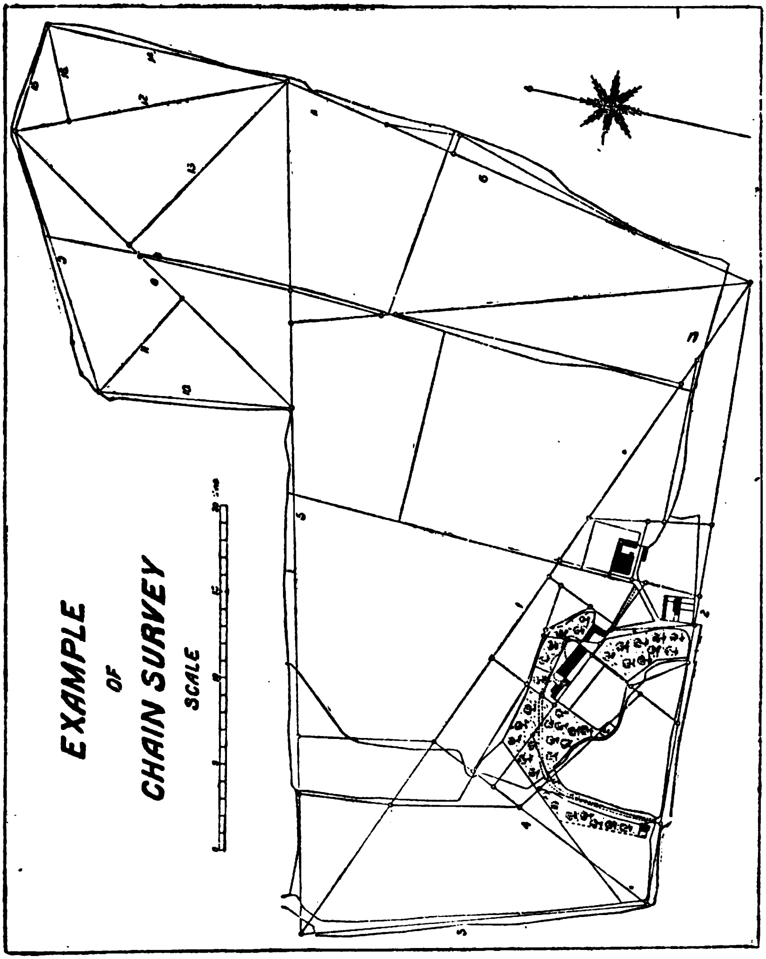

Diagram 1.—Chain Survey.

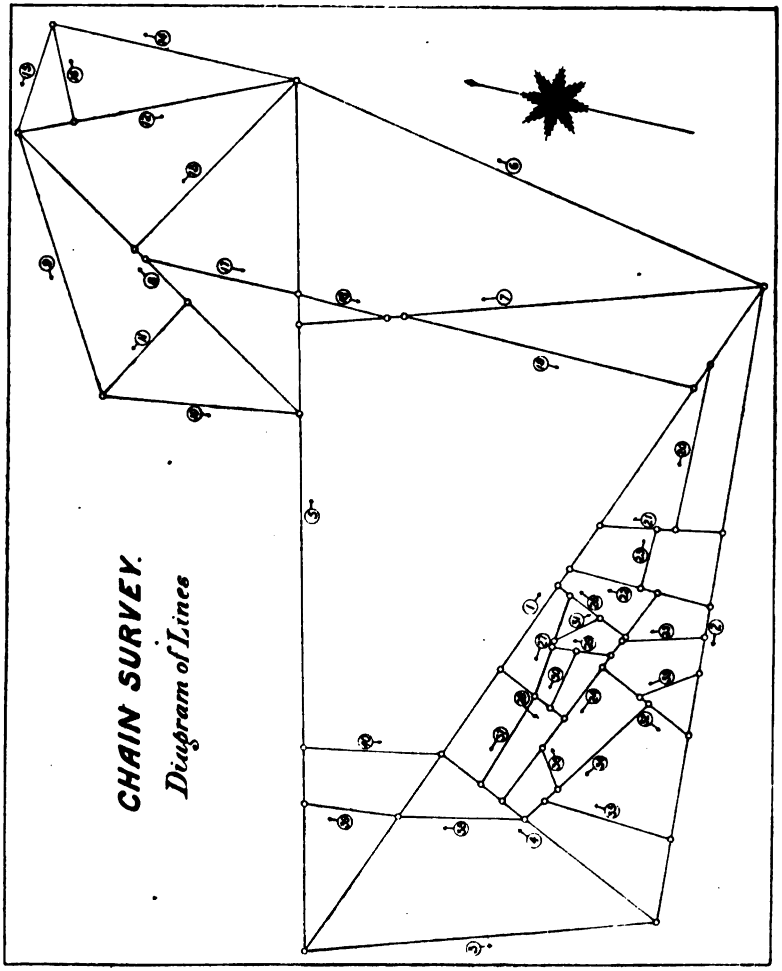

Diagram 2.—Chain Survey.

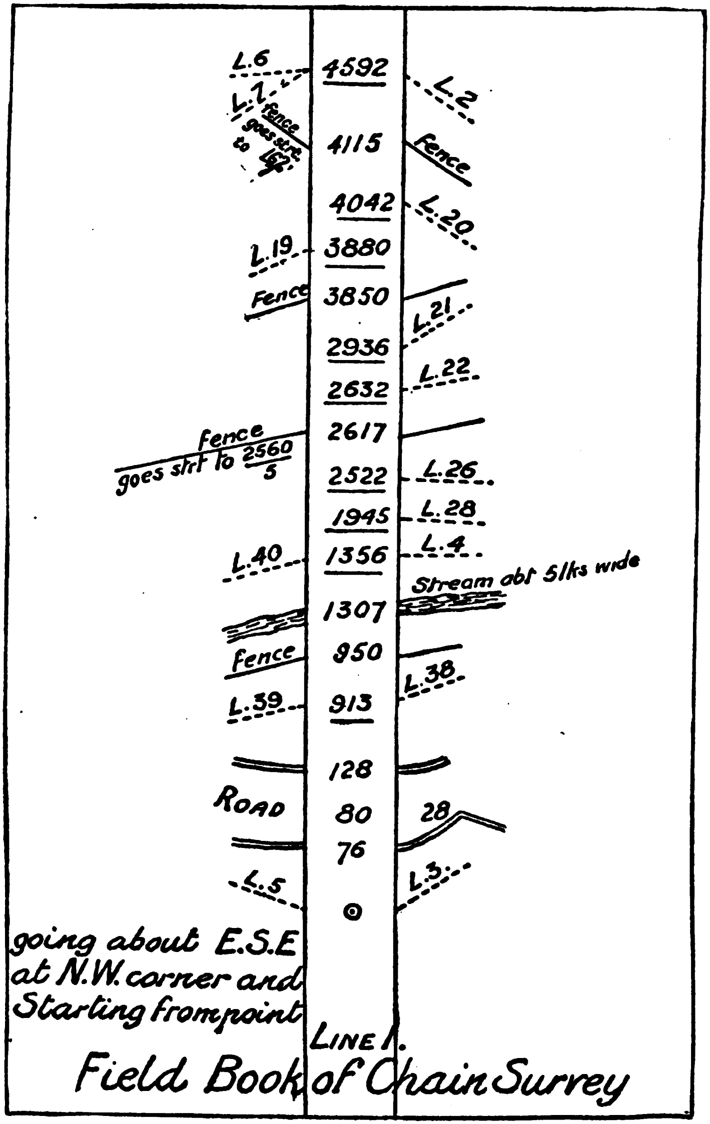
L.6
4592
L.2
L.7
fence goes strt to L.6
4115
fence
4042
L.20
L.19
3880
fence
3850
L.21
2936
L.22
2632
fence goes strt to 2560/5
2617
2522
L.26
1945
L.28
L.40
1356
L.4
Stream abt 5lks wide
1307
fence
950
L.38
L.39
913
128
ROAD
80
28
76
L.5
L.3
going about E.S.E at N.W. corner and Starting from point
LINE 1.
Field Book of Chain Survey

Diagram 3.

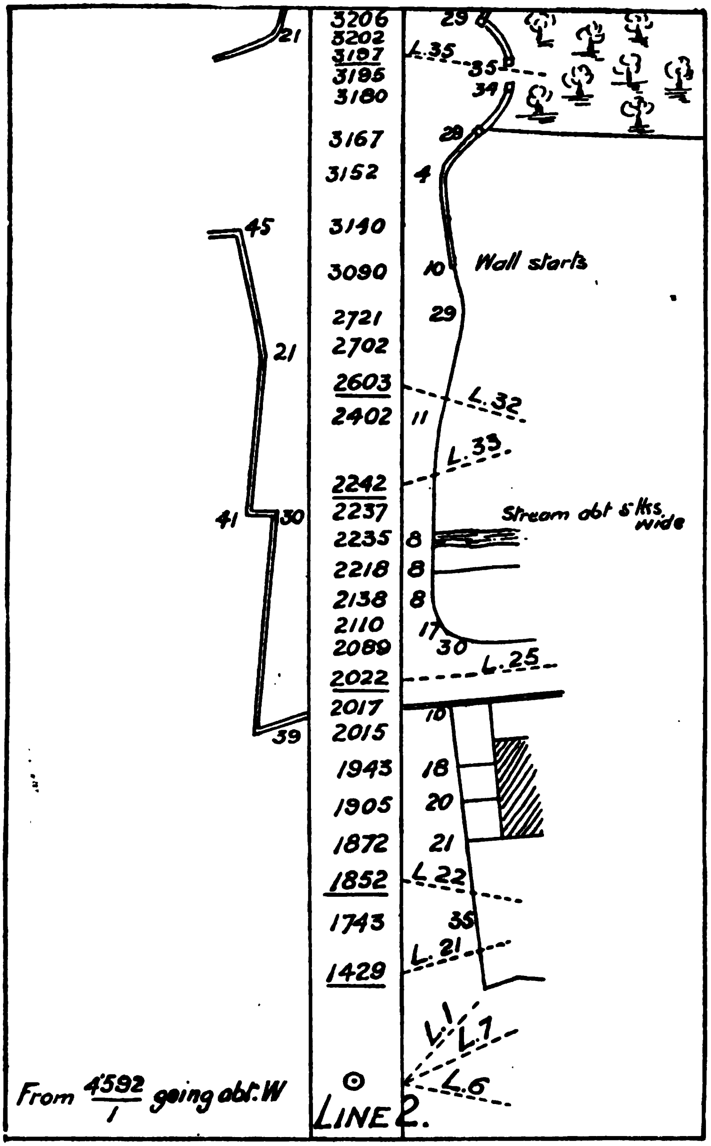

Diagram 4.—Field Book of Chain Survey.

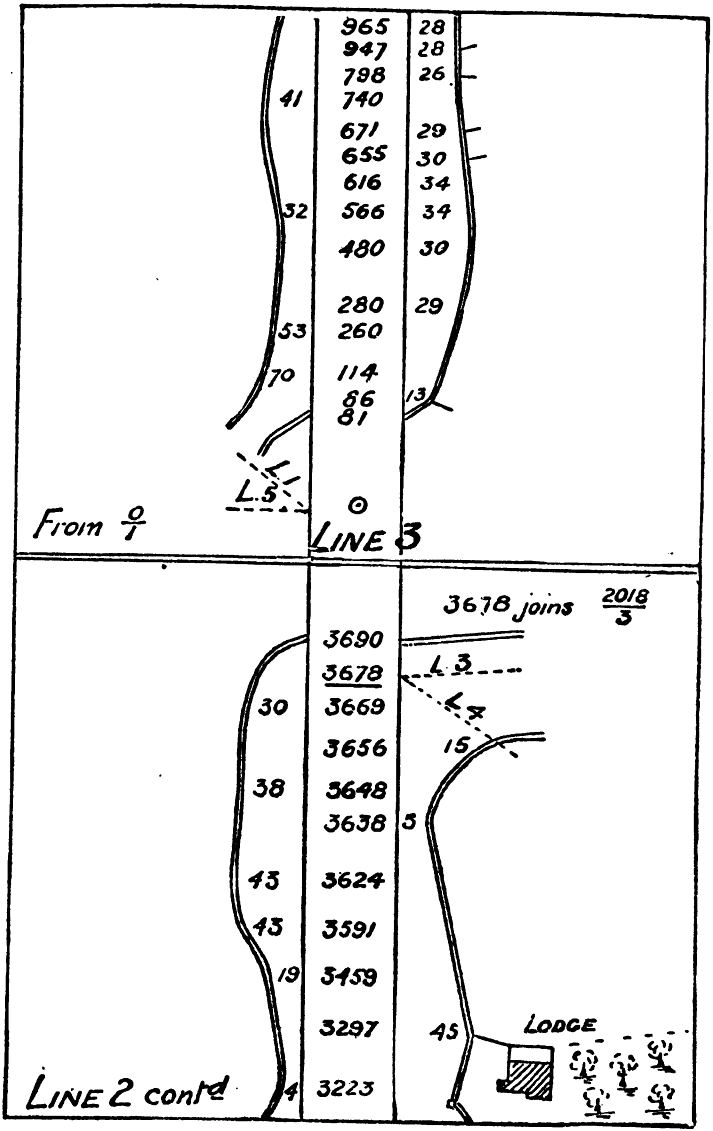

Diagram 5.—Field Book of Chain Survey.

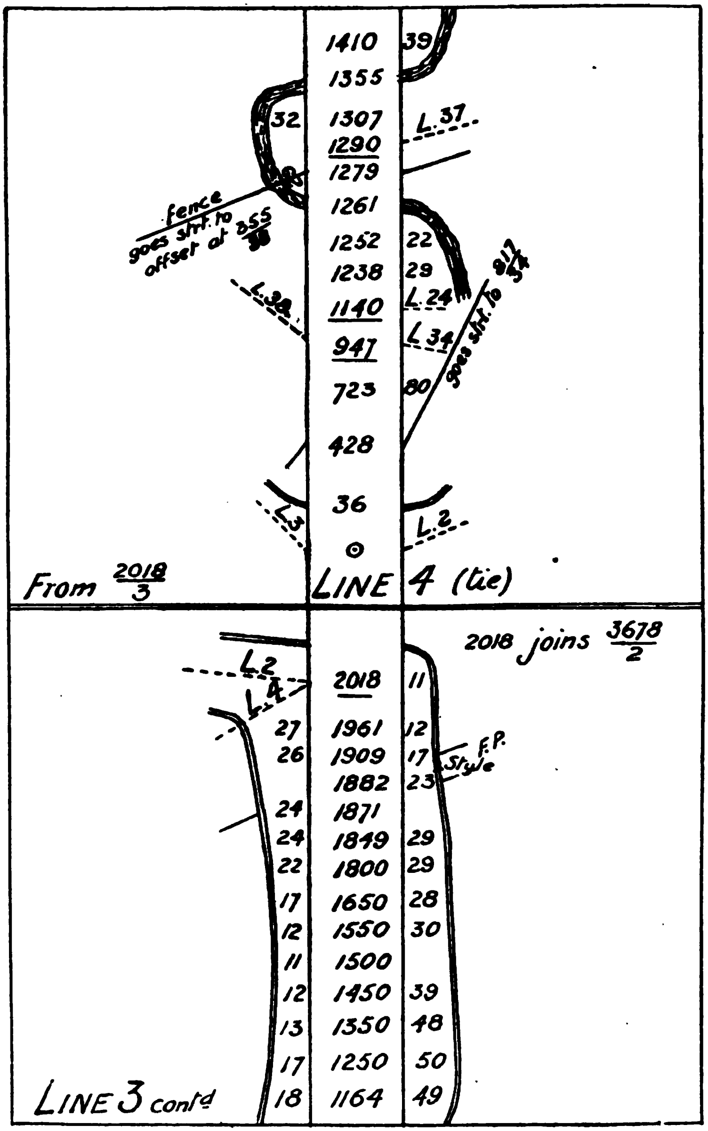

Diagram 6.—Field Book of Chain Survey.

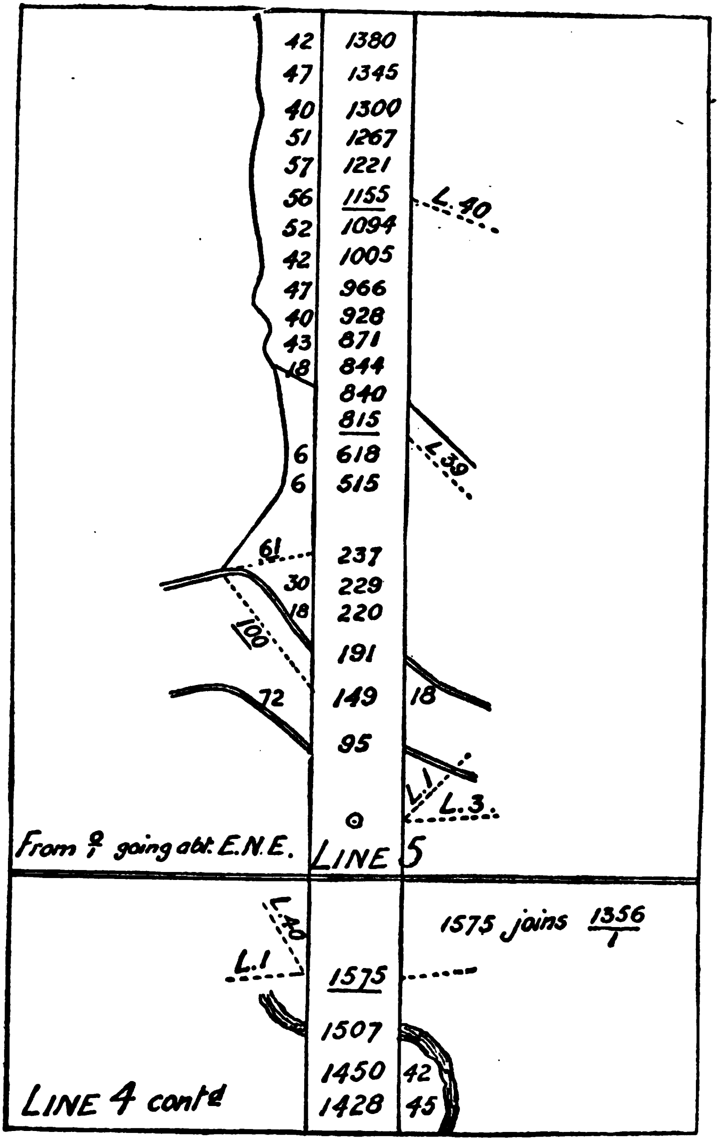

Diagram 7.— Field Book of Chain Survey.

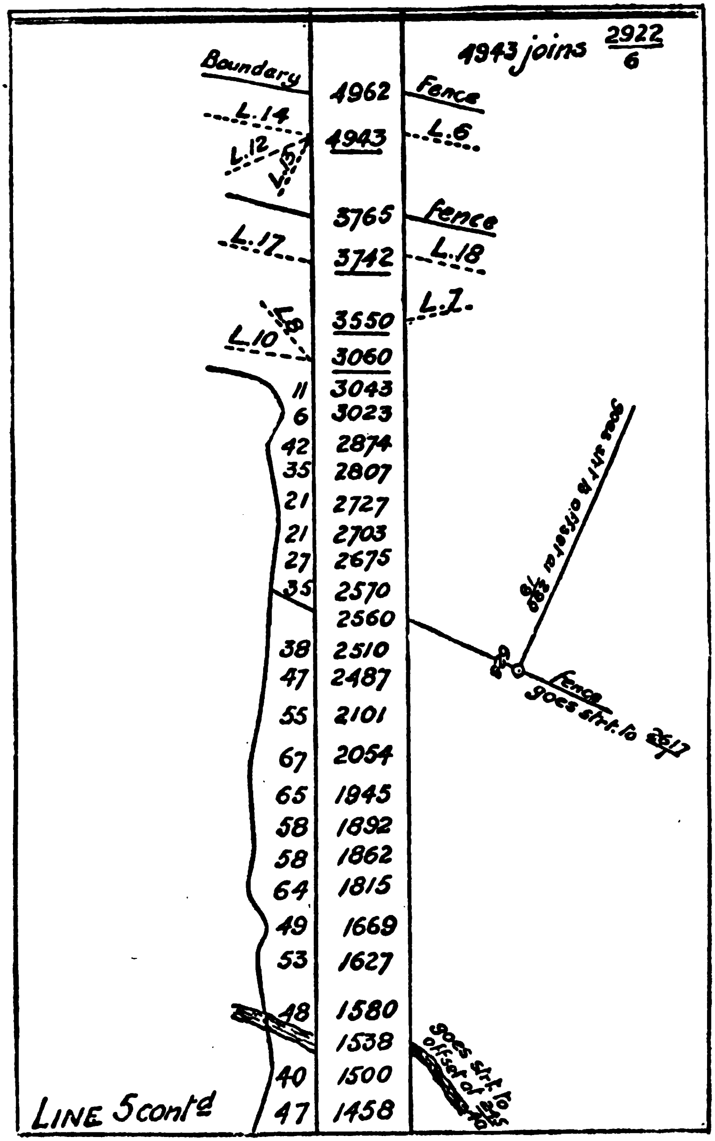

Diagram 8.—Field Book of Chain Survey.

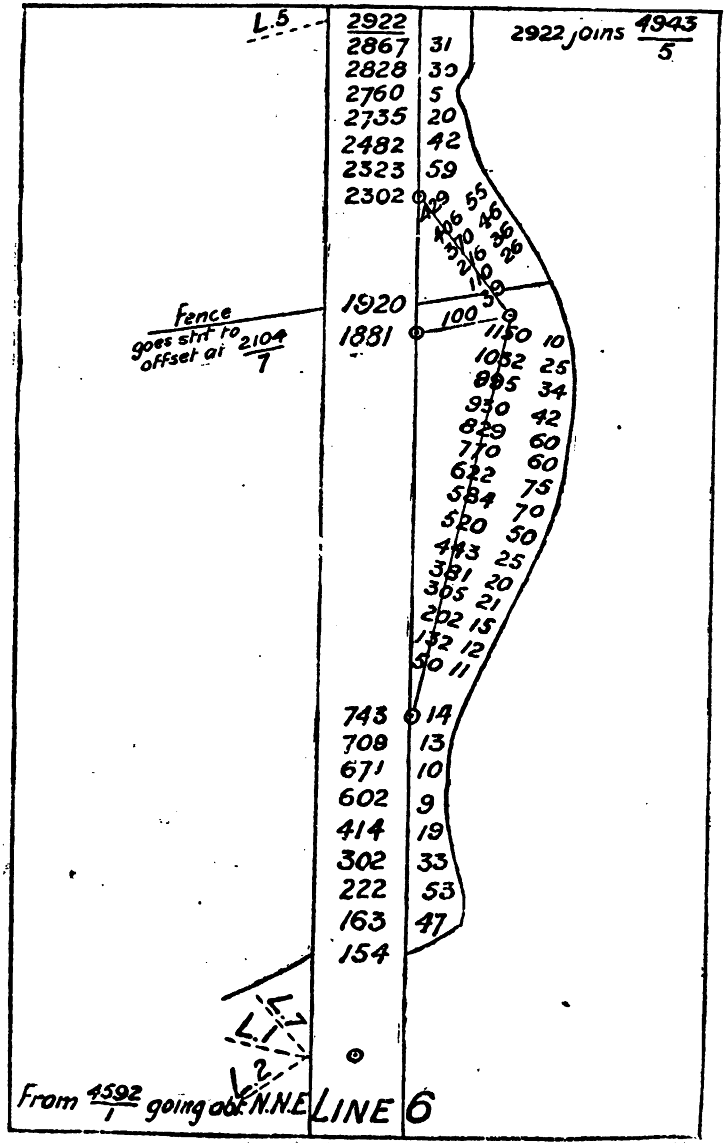

Diagram 9.—Field Book of Chain Survey.

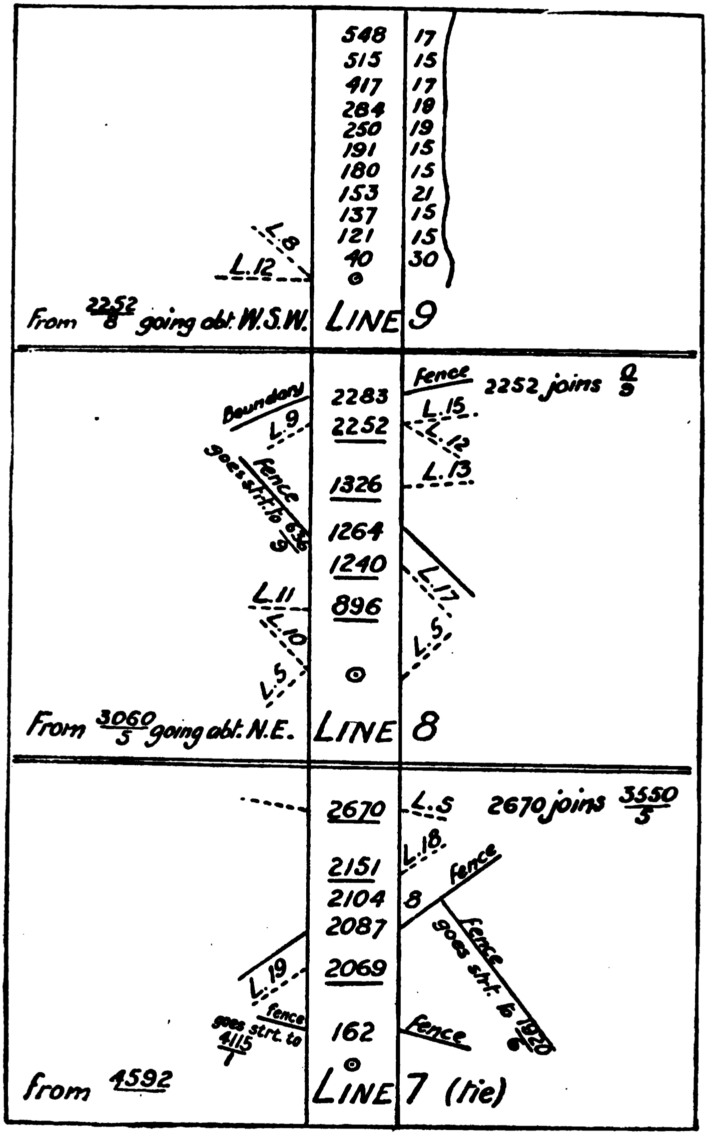

Diagram 10.—Field Book of Chain Survey.

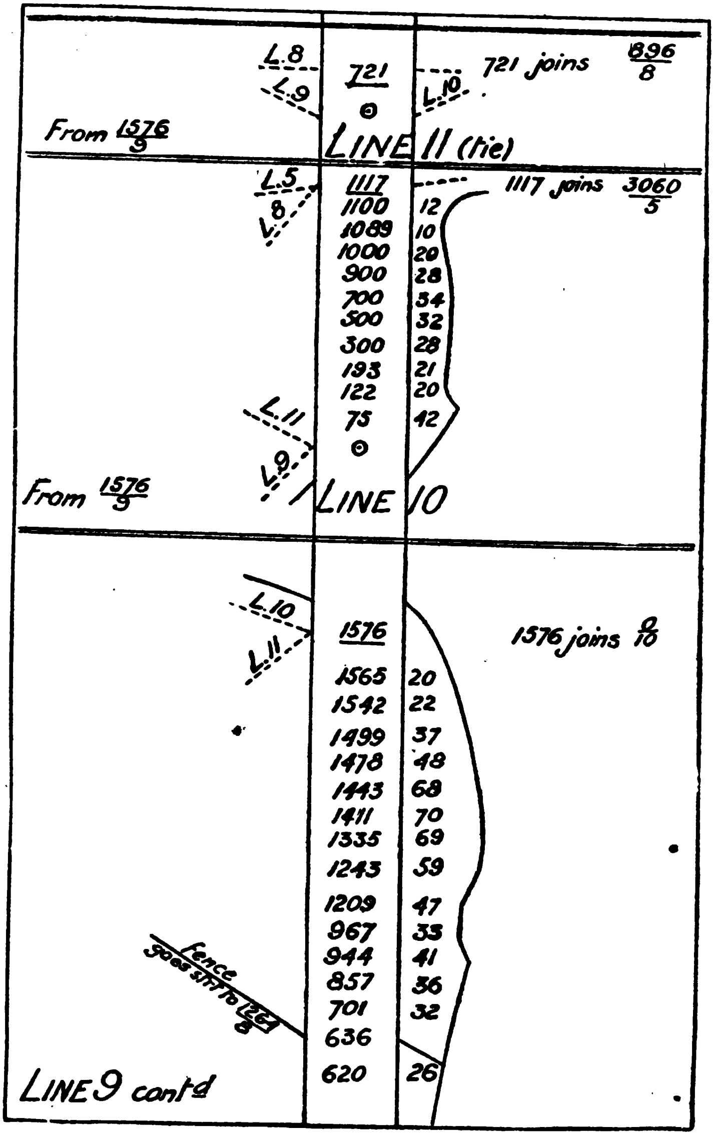

Diagram 11.—Field Book of Chain Survey.

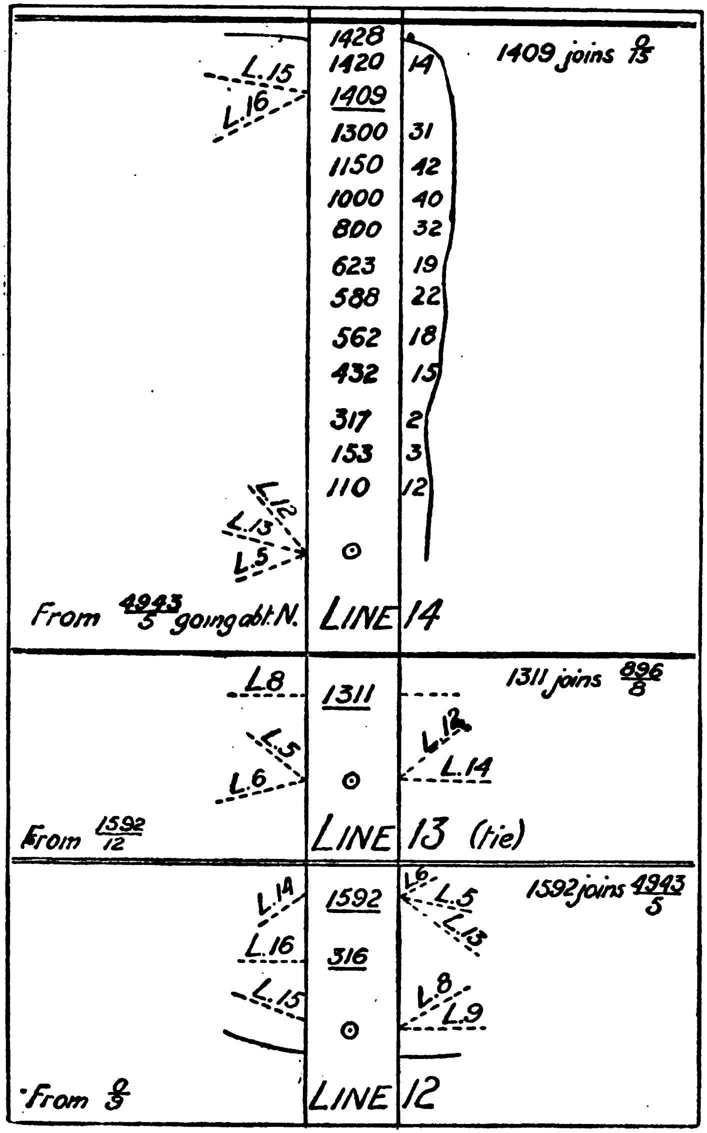

Diagram 12.—Field Book of Chain Survey.

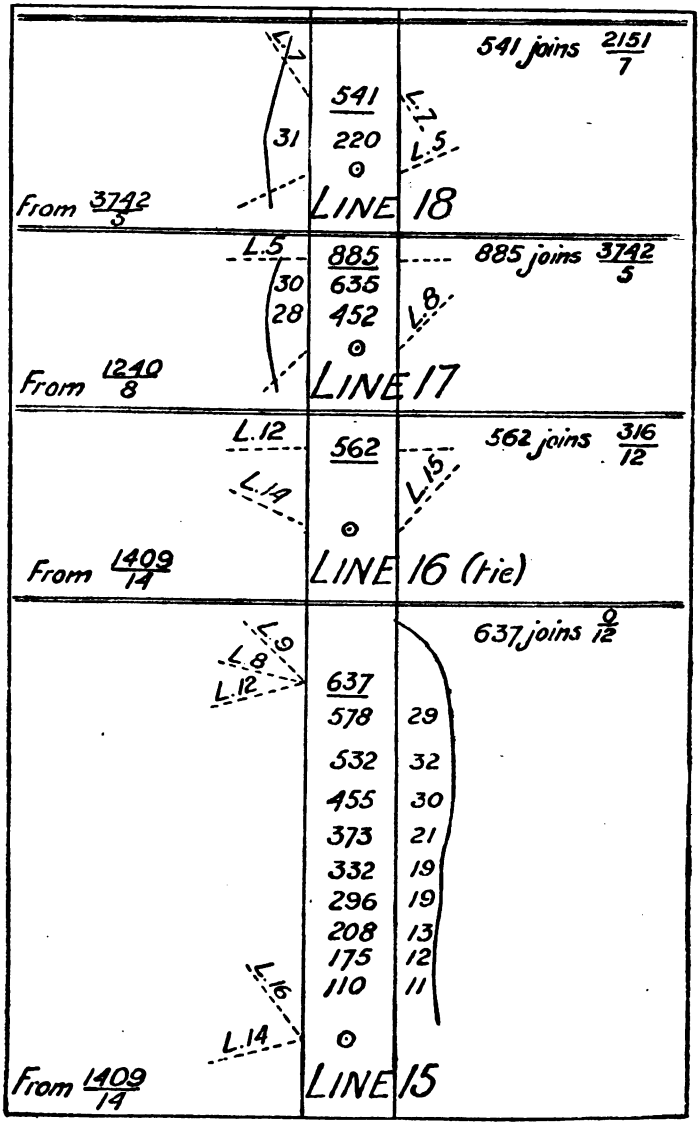

Diagram 13.—Field Book of Chain Survey.

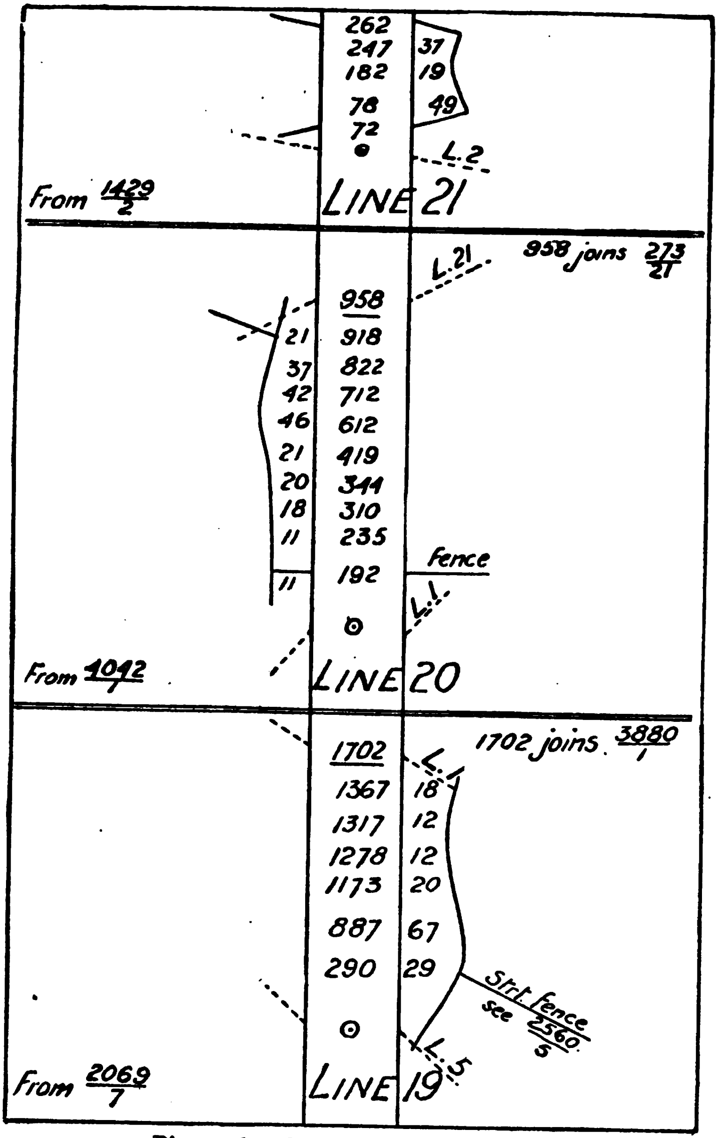

Diagram 14.—Field Book of Chain Survey.

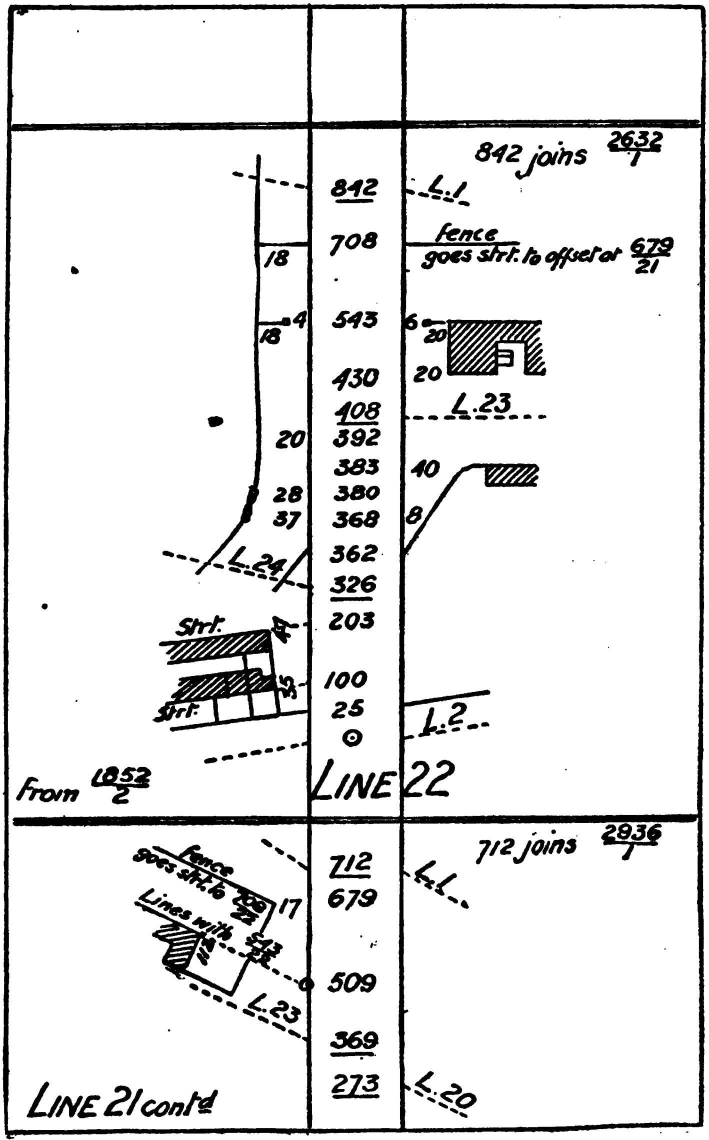

Diagram 15.—Field Book of Chain Survey.

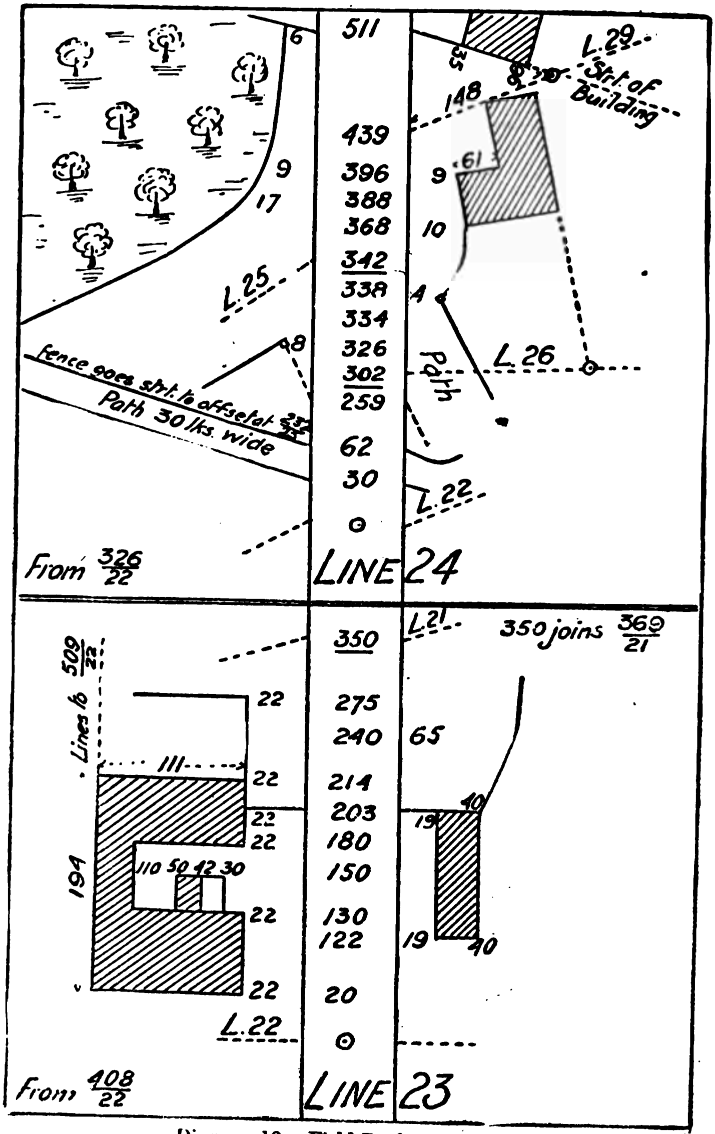

Diagram 16.—Field Book of Chain Survey.

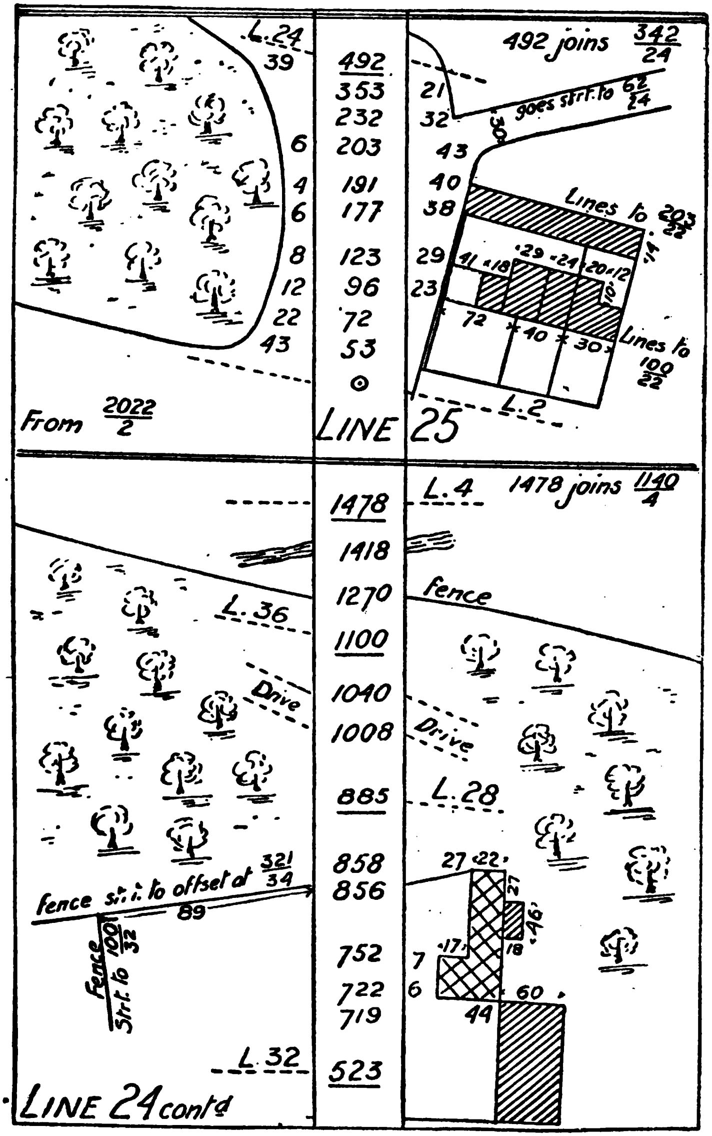

Diagram 17.—Field Book of Chain Survey.

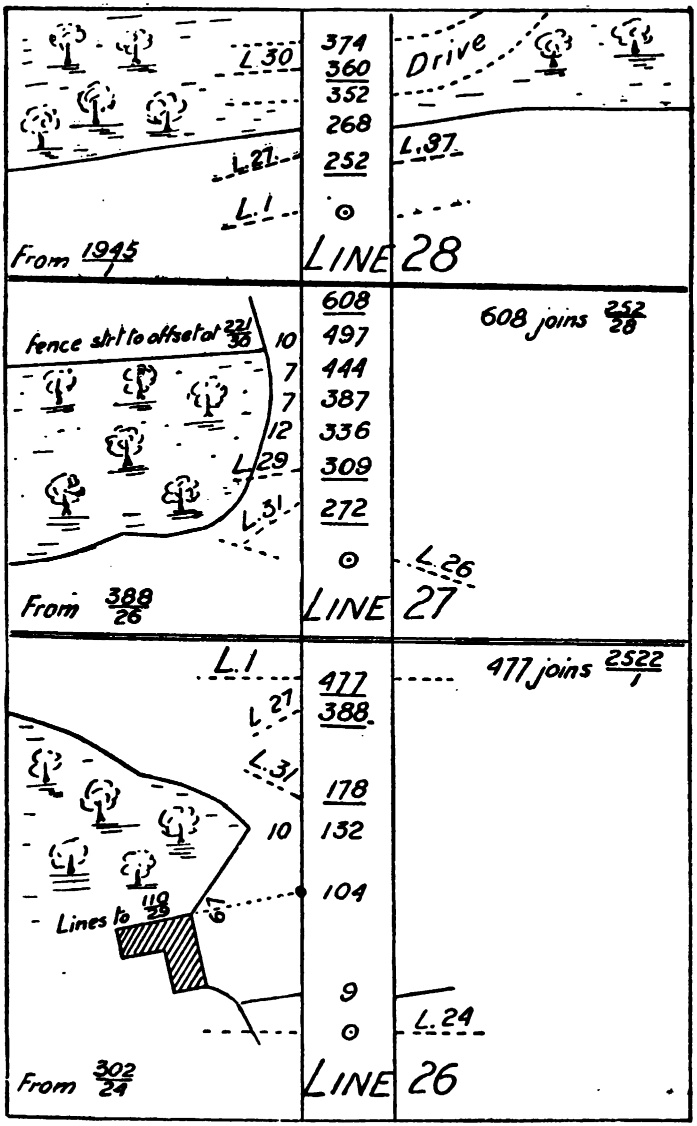

Diagram 18.—Field Book of Chain Survey.

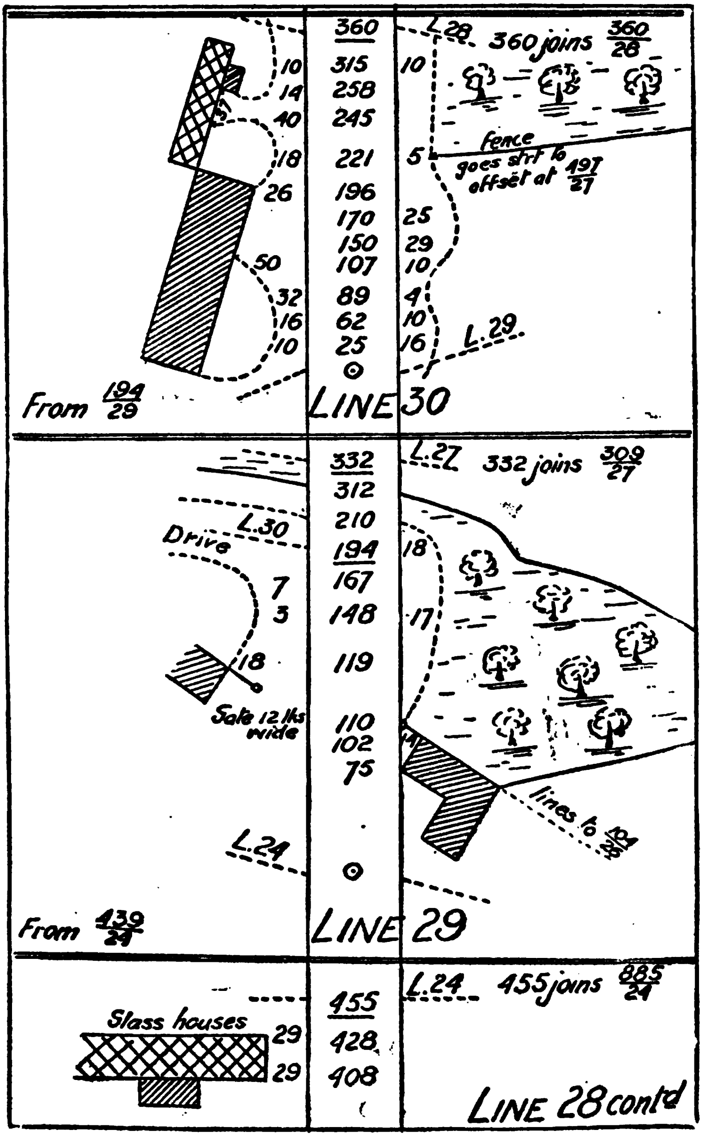

Diagram 19.—Field Book of Chain Survey.

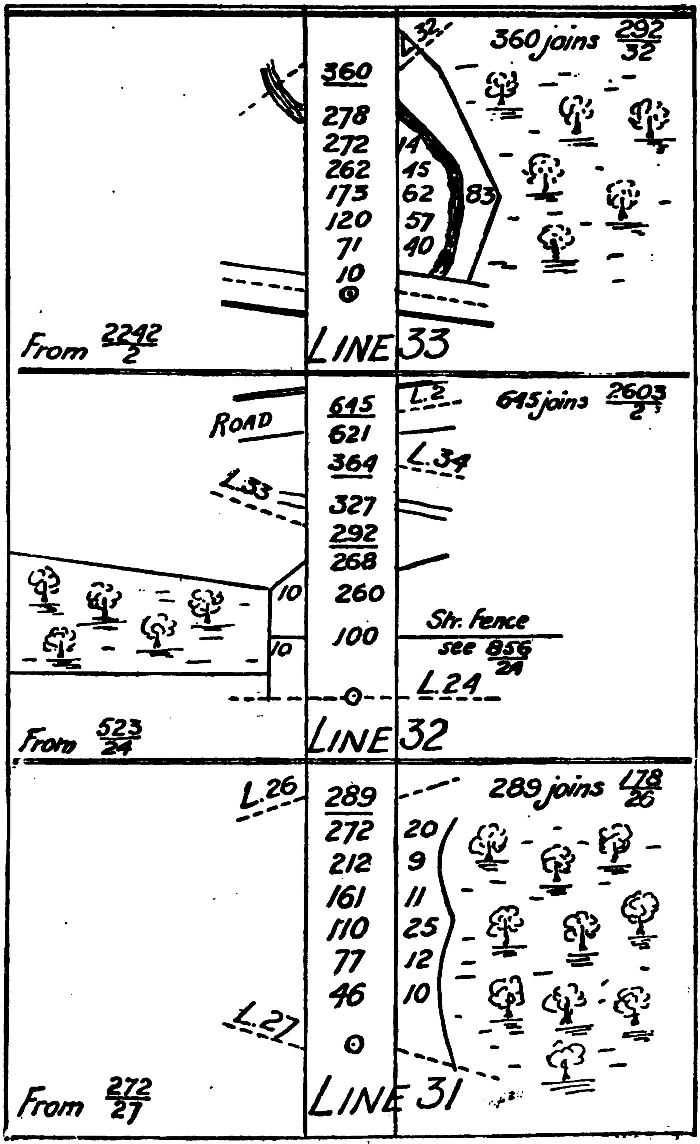

Diagram 20.—Field Book of Chain Survey.

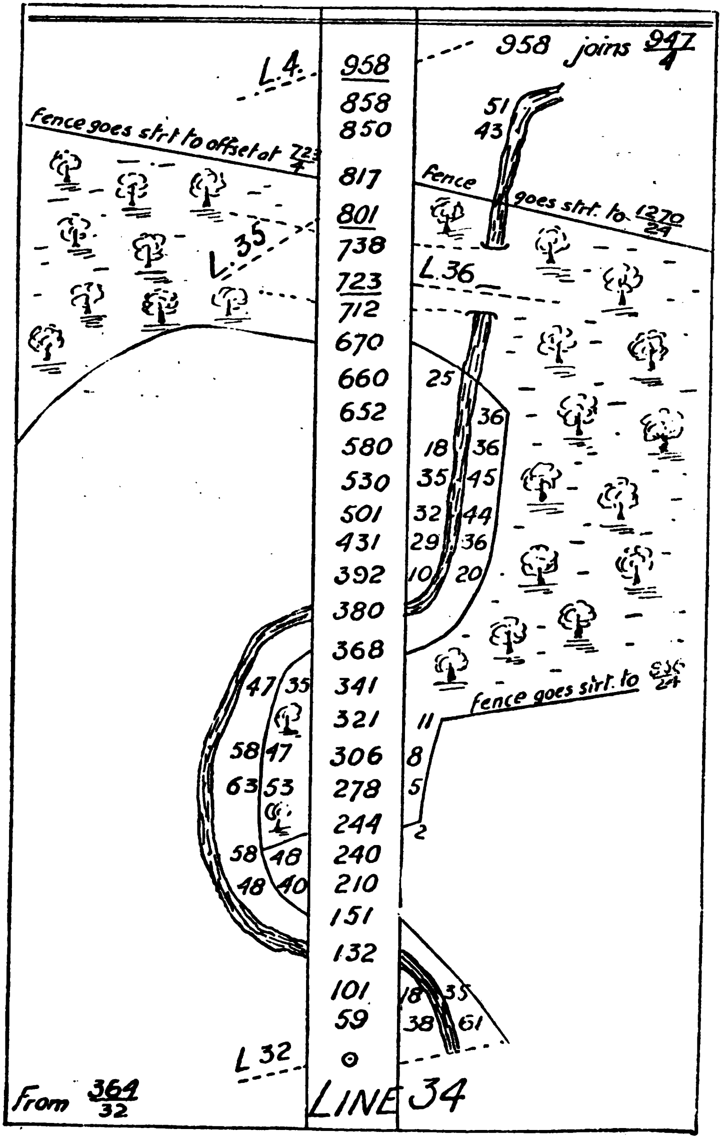

Diagram 21.—Field Book of Chain Survey.

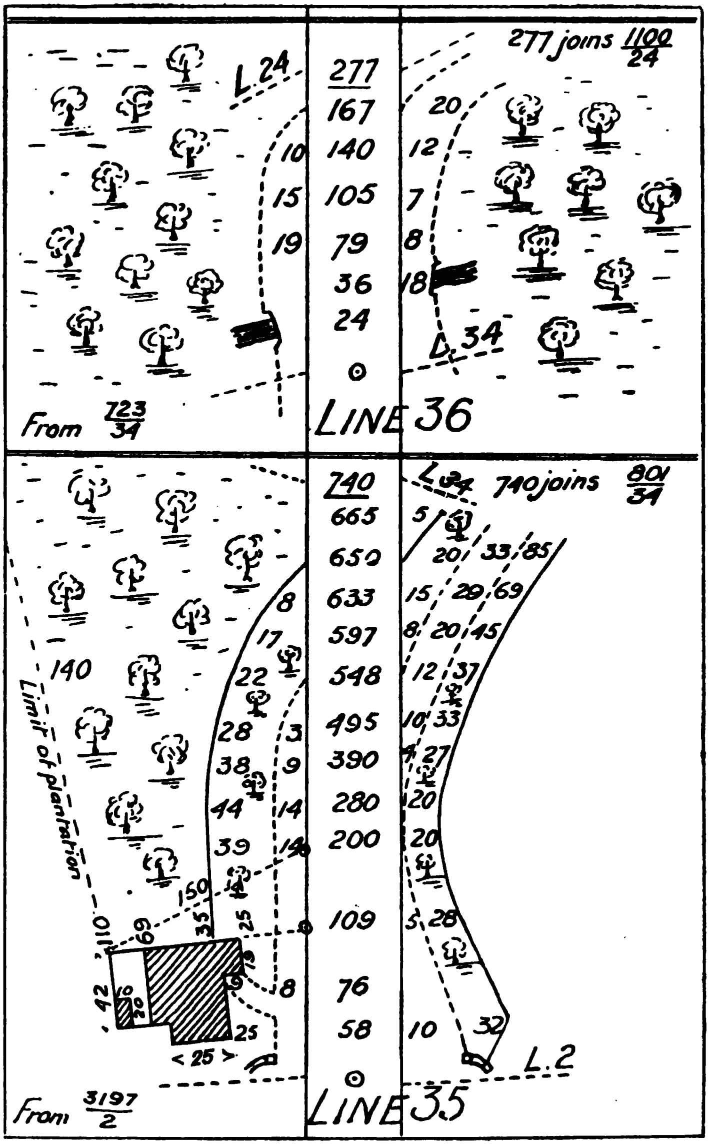

Diagram 22.—Field Book of Chain Survey.

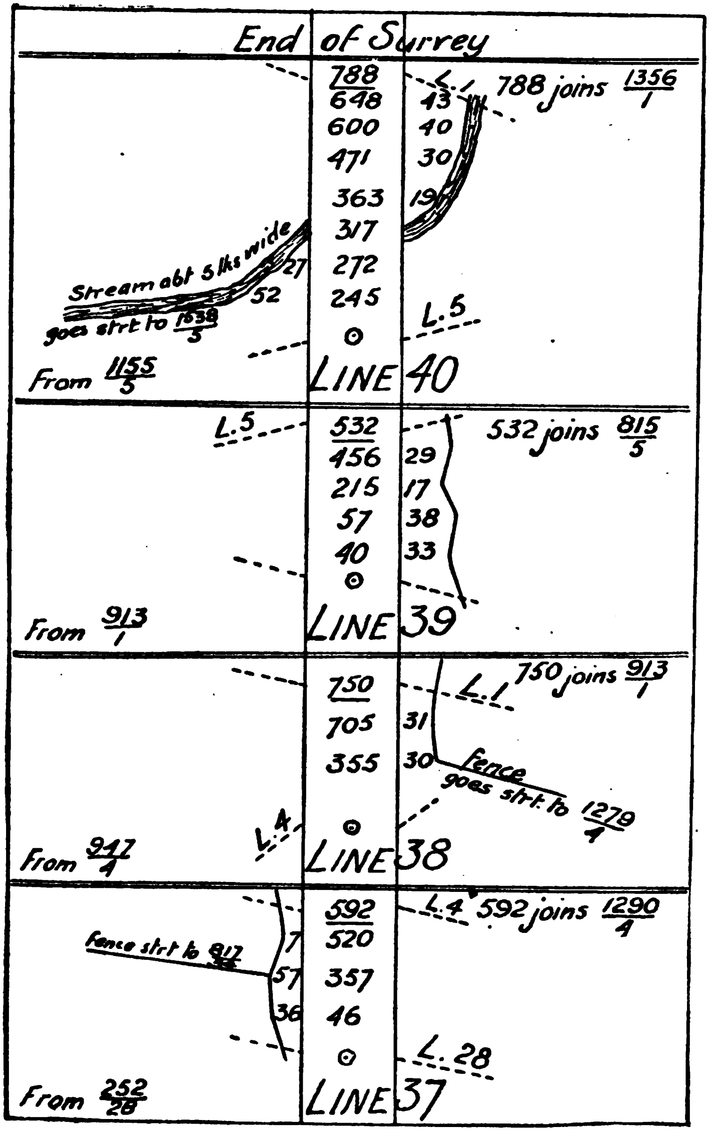

Diagram 23.—Field Book of Chain Survey.

CHAPTER IV.

TRAVERSE SURVEYING.

Application and Definition.—This method of surveying being the only one available for the underground workings of a mine, is of prime importance to mine surveyors. Its use is not confined to underground work, the method having a fairly wide range of application at the surface.

As briefly explained in Chapter I., it consists essentially in measuring the distances and directions of a series of connected straight lines or "drafts," which follow approximately the course of a roadway, boundary, or the like. The distances are measured direct by any of the methods already described, the direction of each line being determined by the angle which it makes with some convenient standard line of reference, measured with the aid of instruments specially designed for the purpose. For the sake of brevity a traverse survey is frequently spoken of simply as a "traverse."

Closed Traverse.—Wherever possible a traverse should be arranged so that the lines form a complete circuit in themselves, or connect points whose relative positions have been previously determined, such a traverse being termed "closed," and its closure on plotting or as proved by calculation affords the most convincing proof of accuracy of both the field and office work of the survey.

Direction of Traverse.—In order to avoid confusion in expressing the directions of the lines, a traverse is normally considered to run in one direction only—viz., from the point at which the survey is commenced, and which is referred to as the "point of origin," towards the finishing point, and the normal direction of each of the lines corresponds with that of the traverse.

Fig. 11 represents the arrangement of the lines of a traverse along a portion of a roadway. The standard line of reference is represented by the line SN, O being the point of origin of the traverse, the normal direction of which is OABCDE.

Lines of Reference or Meridians.—The standard line of reference to which the directions of the lines are referred may be any line most convenient for the purpose. In practice this is generally found to be either the geographical or true meridian, the magnetic meridian, or one of the lines forming part of the traverse. In the last-mentioned case the line may conveniently be assumed to be a true meridian, the northerly direction of which is in the normal direction of the traverse, this assumption being made clear in all notes and on all plans relating to the survey.

The geographical or true meridian of a point on the earth's surface may be defined as the imaginary line which passes through the point and through the north and south geographical poles. In plane surveying the line may be considered as being straight, and the meridians of all the points contained by the survey as being parallel. The methods of determining the true meridian are dealt with in Chapter XII.

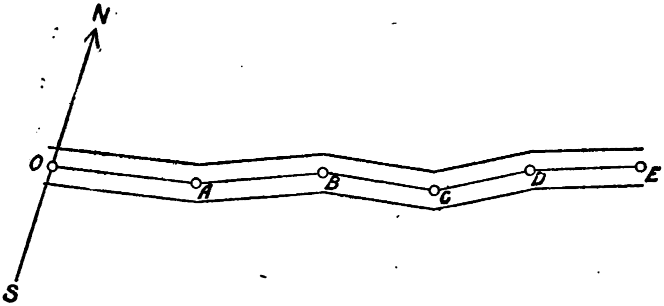

Fig 11

The magnetic meridian of a point on the earth's surface, owing to the variations in the earth's magnetism, is somewhat difficult to define concisely; for practical purposes it may be considered as being the imaginary straight line passing through the centre line of a symmetrical magnetised bar freely suspended from its centre at the given point, when in its mean daily position. The variation in direction of the magnetic meridian at different times and at different points on the earth's surface, even within comparatively limited areas, requires to be taken into account in using it as a line of reference for the directions of traverse surveys, and the following chapter is devoted to this subject.

Horizontal Circle.—As established by long usage, the normal graduation of the horizontal circle used in surveying instruments and protractors for setting out angles on paper is shown in Fig. 12 by the outer numbers. As will be seen, the graduation progresses in a clockwise direction, and this system is followed in the conception of the imaginary horizontal circle used in expressing the directions of lines. A line drawn from the centre of the circle to the zero of the graduations represents the reference line running in its standard direction.

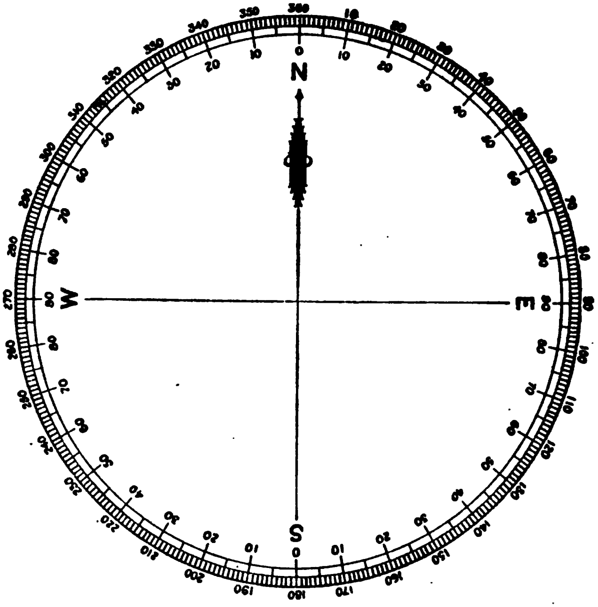

Fig. 12.

Azimuth.—The azimuth of a line is the angle it forms with the true meridian as measured on the imaginary horizontal circle, the starting point of the line being considered to be at the centre of the circle, the line being drawn in its normal direction to the circumference. When the line of reference is not the true meridian, the direction of the line measured as described is termed the "magnetic" or "assumed" azimuth. The term azimuth is synonymous with "meridian bearing," and the less frequently used, though expressive term "whole circle bearing."

Quadrant Bearing.—For purposes of calculation it is sometimes convenient to revert to the older system of notation used in expressing the directions of lines with reference to the cardinal points of the compass. In this, which is shown by the inner set of numbers in Fig. 12, the north and south points are both taken as zeros, the graduation progressing towards the east and west from each of these, in a clockwise direction in the north-east and south-west quadrants, and in a contra-clockwise direction in the south-east and north-west quadrants. It will be seen that, in order to express fully the direction of a line in this system, it is necessary to state the quadrant in which it lies, as well as the angle it forms with the north or south line.

Methods of Traversing.—There are a number of methods employed for measuring the directions of the lines of a traverse which vary with the difference in the principles of the instruments used, and in the manner of using any particular form of instrument. All the methods may be classed under two headings —viz., "loose needle traversing" and "fixed or fast needle traversing." In the former the directions are measured with reference to the magnetic meridian by direct indication with a magnetic compass, and in the latter the angles are measured by means of a vernier independently of the compass. The principal methods employed are dealt with under their respective headings.

Any method of traversing may be supplemented by the method of off-setting, as in chain surveying, using each draft of the traverse as a "chain line."

Plotting of Traverse Surveys.—The methods employed in plotting traverse surveys are dealt with in Chapter XIII.

CHAPTER V.

VARIATIONS OF THE MAGNETIC-NEEDLE.*

Directive Action of the Earth's Magnetism.—The action of the earth's magnetism on a magnetic-needle is directive—*i.e.*, it causes the needle, when free to turn, to come to rest in a definite direction—one end pointing to the north and the other to the south, the end directed to the north is called the "north pole," or more correctly the north-seeking pole of the needle, the other the "south pole" or "south-seeking pole." Magnetic forces act through most solids and liquids as instantaneously and with as great intensity as through the air.

The position taken up by the needle is affected by the proximity of masses of iron or that of other magnetic bodies, but the absence of such causes of local deviation is assumed in considering the direction taken up by a magnetic-needle for the purposes of the present chapter.

Declination.—At most places on the earth's surface the north and south poles of the magnetic-needle point only approximately to the geographical north and south, and the angle formed by the direction of the needle with the true meridian is called the "declination of the magnetic-needle." In using the magnetic-needle for making underground surveys it is assumed that the declination at a point below the surface coincides with that at the corresponding point at the surface of the earth.

The declination at different points on the earth's surface varies very considerably, and at the same point it does not remain constant, but is subject to continual variations. These are either regular or irregular. Under regular variations are included "secular" and "diurnal variations."

Secular Variations.—Observations of the amount and direction of these variations have been made in all parts of the world. The first observation appears to have been made in Paris in the year 1541. The declination of the needle was at that date easterly, and amounted to 7°. In 1550 it was 8°, whilst in 1580 it amounted

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[*] See paper on "Terrestrial Magnetism in Relation to Mine-Surveying," by C. Chree, Sc.D., LL.D., F.R.S. *Trans. I. of M.E.*, vol. lv., p. 223.

to 11° 30′. Thus, between the years 1541 and 1580 the magnetic meridian veered 4° 30′ further towards the east. From 1580 the declination decreased, the magnetic meridian moving towards the west, until in 1666 there was no variation; the magnetic and true meridians coinciding. Ever since that date, the variation has been westerly, attaining its maximum of 22° in 1820, and then gradually decreasing, so that the magnetic meridian is now gradually approaching the true meridian.

The magnetic history of Paris does not apply to London; every place, as far as has been ascertained, has a magnetic history of its own. The following table shows the change in the position of the magnetic-needle near London from the earliest observations up to the present time :—

Date.	Declination.	Date.	Declination West.	Date.	Declination West.
1580	11° 15′ E	1817	24° 36′	1871	20° 10′
1622	6° 00′ E	1818	24° 38′	1872	20° 00′
1634	4° 06′ E	1819	24° 36′	1873	19° 58′
1657	0° 00′	1820	24° 34′	1874	19° 52′
1665	1° 22′ W	1858	21° 54′	1875	19° 41′
1672	2° 30′ W	1859	21° 47′	1876	19° 32′
1692	6° 00′ W	1860	21° 40′	1877	19° 22′
1723	14° 17′ W	1861	21° 32′	1878	19° 14′
1748	17° 40′ W	1862	21° 23′	1879	19° 06′
1773	21° 09′ W	1863	21° 13′	1880	18° 57′
1787	23° 19′ W	1864	21° 03′	1881	18° 50′
1795	23° 57′ W	1865	20° 59′	1882	18° 45′
1802	24° 06′ W	1866	20° 51′	1883	18° 40′
1805	24° 08′ W	1867	20° 40′	1884	18° 32′
1806	24° 15′ W	1868	20° 33′	1885	18° 25′
1809	24° 22′ W	1869	20° 26′	1900	16° 52′
1812	24° 28′ W	1870	20° 19′	1910	16° 03′

From this table it appears that the magnetic-needle has required 300 years (1580-1880) to move through an arc of $11^\circ\,15' + 24^\circ\,38' + (24^\circ\,38' - 18^\circ\,57') = 41^\circ\,34'$. The average annual movement was consequently 8¼′. From 1881 to 1910 the average annual movement was about 5·8′. The figures given in the table from 1858 are the mean values of the magnetic declination as determined at the Kew Observatory.

At Newcastle and Swansea the declination is about 1° 45′ greater than at London; at Liverpool 2°, at Edinburgh 3°, and at Glasgow and Dublin about 3° 50′ greater. At Yarmouth and Dover the declination is about 40′ less than at London.

The mean value of the magnetic declination for any particular place in Great Britain, at which no magnetic observations are made, can generally only be inferred from the map prepared in 1872 by Sir F. J. Evans. This is given in the *Philosophical Transactions*, 1872, vol. 162. Allowance must be made for the change which has since occurred. A similar map of England and Wales is published every year by the *Colliery Guardian*.

In certain parts of the earth, the magnetic and true meridians coincide. The irregularly curved imaginary line joining the points where there is no declination is called the *agonic line*. Such a line cuts the east of South America, and, passing east of the West Indies, crosses the United States, passing just east of Charleston, South Carolina, and just west of Detroit, Michigan. It then passes through the North Pole, crosses Lapland to the Caspian, cuts the east of Arabia, and passes through Western Australia to the South Pole.

Isogonic lines are imaginary lines joining the places on the earth's surface whose declinations are equal at any given time. Maps on which such isogonic lines are shown are called *declination maps*, and a comparison of these in various years shows the variation to which the declination is subject.

The great variation in the declination shows the necessity of recording the date and declination of the needle on all mine-plans, with a note stating whether the bearings given were magnetic bearings, or were reduced to the angles, which the lines would form with the true meridian.

The antiquity of the workings on an old undated plan may be approximately ascertained from the meridian line shown on it. Thus, if a plan is found to be constructed to a meridian with a declination of 24° 0′ west, it is reasonable to suppose that it was drawn about the year 1800, for, according to the table, the declination in 1802 was 24° 6′ west.

Diurnal Variation.—On observing a magnetic-needle throughout an entire day, it will be found that the variation does not remain constant, but changes more, and in a different way, than is demanded by the secular change. Observations at London show that at about 8 a.m. the needle reaches its furthest point east, and that at 1 p.m. it shows the greatest westerly deviation from the mean magnetic meridian. The declination then decreases until 10 p.m., when it remains stationary until 4 a.m. It then decreases again until 8 a.m., by which time it has again reached its furthest point east. The needle stands at its mean position a little after 10 a.m., and a little before 7 p.m. The diurnal changes are much the same over the whole of the northern hemisphere, though the amount differs.

The following table shows the diurnal variation for London (Kew), Trevandrum in Madras, and Hobart Town in Tasmania. Of these places, the first is a station in middle latitude (northern hemisphere), the second is an equatorial station, and the third a station in middle latitude (southern hemisphere).

Hour.	London.	Trevandrum.	Hobart Town.
	Minutes.	Minutes.	Minutes.
12 a.m.	−5·13	−0·61	+1·35
1 p.m.	−6·19	−0·45	+3·50
2 p.m.	−5·81	−0·15	+4·55
3 p.m.	−4·28	+0·13	+4·40
4 p.m.	−2·60	+0·28	+3·35
5 p.m.	−1·26	+0·24	+2·00
6 p.m.	−0·39	+0·13	+1·15
7 p.m.	+0·22	+0·04	+0·50
8 p.m.	+0·68	−0·05	0·00
9 p.m.	+0·99	−0·08	−0·55
10 p.m.	+1·24	−0·06	−0·90
11 p.m.	+1·37	+0·01	−1·00
12 p.m.	+1·43	+0·09	−0·95
1 a.m.	+1·29	+0·13	−0·75
2 a.m.	+1·39	+0·15	−0·55
3 a.m.	+1·51	+0·09	−0·40
4 a.m.	+1·88	+0·02	−0·40
5 a.m.	+2·51	+0·01	−0·75
6 a.m.	+3·07	+0·18	−1·30
7 a.m.	+3·58	+0·32	−2·15
8 a.m.	+3·80	+0·24	−3·25
9 a.m.	+2·95	+0·06	−3·70
10 a.m.	+0·46	−0·22	−3·00
11 a.m.	−2·68	−0·50	−1·15

In this table deflections towards the magnetic east are reckoned positive, deflections towards magnetic west negative.

The diurnal variations are found to vary with the seasons of the year. They are much greater in summer than in winter. The cause of the variations is frequently ascribed to the influence of sunlight. Other influences appear to be at work, as is shown by the fact that the variations of the declination of a magnetic-needle at a place on the earth's surface coincide with the variations observed simultaneously underground. This was found to be the case at a magnetic observatory established, at a depth of 3,280 feet below the surface, at Przibram in Bohemia. Similar results were obtained in 1905 at the Tamarack copper mine, Lake Superior, the deepest mine in the world, at a point 4,760 feet below the surface. The slightest movements of the magnetic-needle observed at the earth's surface occur at the same time and to the same extent even at the greatest depths to which mining is able to penetrate.

Irregular Variations.—The declination is subject to sudden temporary deviations from the mean position, which are quite irregular in their occurrence, and amount in extreme cases to 1° or 2°. Such disturbances are known as *magnetic storms*, and appear to be coincident with the appearance of the aurora borealis, earthquakes, and volcanic eruptions. The cause of these storms has not yet been determined. Sabine, however, found that they are most frequent every eleven years when the spots on the sun are most numerous. Experience shows that places of the same longitude have similar disturbances at the same time, that those on opposite sides of the globe differing by 180° of longitude, have disturbances equal in amount but opposite in direction, and that places situated 90° west or east of the disturbed regions have practically no disturbance.

Magnetic storms are not to be confused in any way with atmospheric or thunder-storms, which do not affect the declination, nor is the prevalence of a magnetic storm revealed by any visible peculiarity in the behaviour of the needle during surveying operations.

Notices of the occurrence of magnetic storms are published by the Superintendent of the Magnetic Department at Greenwich in the mining journals, and deserve the careful attention of mine-surveyors. No reliance should be placed on a survey made at or about the time when a magnetic storm is known to have occurred.

Determination of Magnetic Declination.—In order to determine the declination at any point, it is necessary to determine the true meridian at the same point; the methods employed for the latter determination are given in Chapter XII.*

For mine-surveying purposes the determination of the absolute declination at any particular time is not generally essential, but a knowledge of the variations is of paramount importance in the keeping up of the working plans for a mine, when the surveying is carried on from a magnetic basis. The extent of the variation should be ascertained at least every six months, and also on each occasion when a particularly important survey is carried out. A quite satisfactory method of procedure is to incorporate in the surface survey a "meridian test line," which should run from side to side of the royalty, and as nearly through the centre as circumstances will permit. It should be permanently marked by substantial blocks of stone firmly secured in the ground, a hole being bored in each block, exactly in the line, for the reception of a ranging pole. The magnetic bearing of this test line is taken at a number of points along it, at a time of the day corresponding to the mean declination, using the same instrument as is used in the survey. The mean of these observations is used for setting out the meridian from the test line on the plan. By this means, not only is the secular variation taken into account, but certain errors in any particular instrument are eliminated. If a number of instruments are employed in making the survey, the mean bearing of the test line should be determined with each of the instruments used, and in case of the mean observations varying appreciably from each other, a separate meridian corresponding to each of the mean observations should be set out on the plan, and each used only for plotting the portion of the survey made with the corresponding instrument.

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* See paper on "A Method of Determining the Magnetic Meridian as a Basis for Mining Surveys," by T. Lindsay Galloway. *Trans. I. of M.E.*, vol. lvi., p. 222.

At the time of making the surface survey, the magnetic bearings of selected lines should be observed, with a view to ascertaining whether there are any notable differences in the declination due to locality within the limits of the royalty. If any such differences are found, the plan should be divided up in such a way that areas are obtained over which the declination can be considered as constant at any given time, and a separate meridian test line established on the surface in each of the areas.

The magnetic meridian can be set out on a small scale ordnance map by ascertaining the mean declination for the locality from a declination map such as that issued by the *Colliery Guardian*, previously referred to, and setting off the corresponding angle by means of a protractor from one of the side boundaries of the map, these being geographical north and south lines. If the scale of the map is sufficiently large to admit of points being accurately located, a line should be run on the ground between two well-defined points and the magnetic bearing observed, the angle so obtained being set off from a corresponding line drawn on the map.

The most satisfactory method of obviating the effects of diurnal variations is to carry out the surveys at night, when the declination remains fairly constant and near the mean.

Inclination of the Magnetic-Needle.—If a magnetic-needle is mounted so that it is free to move about its centre of gravity, in a vertical plane (see Fig. 151, p. 408), it does not, at most places on the earth's surface, rest in a horizontal position, but inclines more or less from it. The angle between the needle and the horizontal line is called the *dip* or *inclination* of the needle, provided that the vertical plane in which the needle moves is the magnetic meridian of the plane. The dip varies at different places; at the magnetic equator there is no dip, whilst at the magnetic poles the needle stands vertically.

The dip is not of great importance to mine-surveyors in Britain, as the needles of dials are carefully compensated when sold. Surveyors going abroad with an English dial should be provided with a small sliding balance for the needle, which may be adjusted when necessary, should the dip prove troublesome.

Like the magnetic declination, the dip is subject to secular variations. The following are results of observations near London extending over a series of years :—

Year.	Inclination.	Year.	Inclination.
1576	71° 50′	1880	67° 35′
1600	72° 00′	1881	67° 34′
1720	74° 42′	1882	67° 34′
1800	70° 35′	1883	67° 31′
1830	69° 38′	1884	67° 30′
1850	68° 48′	1885	67° 27′
1865	68° 09′	1886	67° 27′

Recent Magnetic Observations.—The following are the values of the magnetic elements observed at Greenwich during recent years :—

Year.	Mean Declination West.	Mean Inclination.
1887	17° 49·1′	67° 26·6′
1888	17° 40·4′	67° 25·6′
1889	17° 34·9′	67° 24·3′
1890	17° 28·6′	67° 23·0′
1891	17° 23·4′	67° 21·4′
1892	17° 17·4′	67° 19·8′
1893	17° 11·4′	67° 17·8′
1894	17° 4·6′	67° 17·3′
1895	16° 57·0′	67° 14·7′
1896	16° 52·0′	67° 15·0′
1897	16° 46·0′	67° 13·0′
1898	16° 39·0′	67° 12·0′
1899	16° 34·2′	67° 10·2′
1900	16° 29·0′	67° 8·5′
1901	16° 26·0′	67° 6·1′
1902	16° 22·8′	67° 3·4′
1903	16° 19·1′	67° 0·9′
1904	16° 15·0′	66° 57·2′
1905	16° 09·9′	66° 55·5′
1906	16° 03·6′	66° 55·6′
1907	15° 59·8′	66° 56·2′
1908	15° 53·5′	66° 56·3′
1909	15° 47·6′	66° 54·1′
1910	15° 41·2′	66° 52·8′
1911	15° 33·0′	66° 52·1′
1912	15° 24·3′	66° 51·8′
1913	15° 15·2′	66° 50·5′

Dr. C. Chree, Superintendent of the Kew Observatory, has published* the following summary (p. 72) of recent values of declination at the principal magnetic observatories of the world.

In the years 1884 to 1888 Dr. T. E. Thorpe and Sir A. W. Rücker made magnetic observations at 205 places in the United Kingdom. The work was subsequently extended, and the magnetic constants have now been determined at 882 places in Great Britain and Ireland. The results have been published by Sir A. Rücker,† who gives a map showing the true lines of equal declinations for January 1st, 1891. By means of the table of secular change it will be possible to determine the value of the declination at any place in the United Kingdom for some years to come.

The neglect of the secular variation of the magnetic-needle resulted in a sad catastrophe at Wheal Owles, in Cornwall, where,

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* *National Physical Laboratory Report*, 1906, p. 19.

† *Trans. Fed. Inst. M.E.*, vol. ix., 1895, p. 417.

Place.	Latitude.	Longitude.	Year.	Declination.
Sitka, Alaska,	57° 3′ N.	135° 20′ W.	1904	29° 56·7′ E.
Katherinenburg,	56° 49′ N.	60° 38′ E.	1903	10° 18·4′ E.
Copenhagen,	55° 41′ N.	12° 34′ E.	1900	10° 12·2′ W.
Stonyhurst,	53° 51′ N.	2° 28′ W.	1905	17° 53·5′ W.
Hamburg,	53° 34′ N.	10° 3′ E.	1903	11° 10·2′ W.
Wilhelmshaven,	53° 32′ N.	8° 9′ E.	1906	12° 5·4′ W.
Potsdam,	52° 23′ N.	13° 4′ E.	1905	9° 34·3′ W.
Utrecht,	52° 5′ N.	5° 11′ E.	1904	13° 32·7′ W.
Valencia (Ireland),	51° 56′ N.	10° 15′ W.	1906	21° 6·3′ W.
Kew,	51° 28′ N.	0° 19′ W.	1906	16° 28·5′ W.
Greenwich,	51° 28′ N.	0° 0′	1905	16° 9·9′ W.
Brussels,	50° 48′ N.	4° 21′ E.	1904	13° 57·7′ W.
Falmouth,	50° 9′ N.	5° 5′ W.	1906	18° 5·3′ W.
Prague,	50° 5′ N.	14° 25′ E.	1905	8° 43·3′ W.
Jersey,	49° 12′ N.	2° 5′ W.	1906	16° 31·7′ W.
Paris,	48° 49′ N.	2° 29′ E.	1906	14° 51·3′ W.
Munich,	48° 9′ N.	11° 37′ E.	1905	10° 4·6′ W.
Budapest,	47° 53′ N.	18° 12′ E.	1905	7° 3·0′ W.
Odessa,	46° 26′ N.	30° 46′ E.	1899	4° 36·7′ W.
Pola,	44° 52′ N.	15° 51′ E.	1905	9° 0·1′ W.
Nice.	43° 43′ N.	7° 16′ E.	1899	12° 4·0′ W.
Toronto,	43° 47′ N.	79° 18′ W.	1905	5° 42·2′ W.
Perpignan,	42° 42′ N.	2° 53′ E.	1900	13° 37·3′ W.
Naples,	40° 52′ N.	14° 15′ E.	1904	8° 51·1′ W.
Madrid,	40° 25′ N.	3° 40′ W.	1901	15° 35·6′ W.
Coimbra,	40° 12′ N.	8° 25′ W.	1905	17° 1·5′ W.
Baldwin, Kansas,	38° 47′ N.	95° 10′ W.	1904	8° 26·4′ E.
Cheltenham, Maryland,	38° 44′ N.	76° 50′ W.	1904	5° 13·6′ W.
Lisbon,	38° 43′ N.	9° 9′ W.	1900	17° 18·0′ W.
Tokio,	35° 41′ N.	139° 45′ E.	1901	4° 36·1′ W.
Havana,	23° 8′ N.	82° 25′ W.	1905	2° 58·0′ E.
Hong Kong,	22° 18′ N.	114° 10′ E.	1905	0° 8·9′ E.
Bombay,	18° 54′ N.	72° 49′ E.	1905	0° 14·0′ E.
Manila,	14° 35′ N.	120° 59′ E.	1904	0° 51·4′ E
Batavia,	6° 11′ S.	106° 49′ E.	1904	0° 57·5′ E.
Mauritius,	20° 6′ S.	57° 33′ E.	1905	9° 11·3′ W.
Rio de Janeiro,	22° 55′ S.	43° 11′ W.	1905	8° 46·6′ W.
Santiago, Chile,	33° 27′ S.	70° 42′ W.	1904	14° 31·3′ E.
Melbourne,	37° 50′ S.	144° 58′ E.	1901	8° 26·7′ E.
Christchurch, N.Z.,	43° 32′ S.	172° 37′ E.	1903	16° 18·4′ E.

on January 10th, 1893, an irruption of water from an abandoned portion of the workings led to the loss of twenty lives. According to Mr. J. Henderson,* this catastrophe was found on investigation to have been due to ignorance of the secular variation, as in the plan of the underground workings, periodically kept up to date with care, the same magnetic meridian was used for a period of forty years. Thus, the levels of some extensive old workings full of water were holed at a point where the plan showed a safe barrier of solid ground.

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* *Ibid.*, vol. viii., 1895, p. 273.

Considerable attention has been devoted on the Continent to the variation of the needle, and magnetic observatories have been erected in most of the mining districts. At Beuthen, in Upper Silesia, for example, a photographic recording declinometer has been installed. The records are copied every five days at the Breslau Mining Office, and issued to all the mine-surveyors of the district. A similar instrument has been in operation at Bochum, in Westphalia, since 1895, and Mr. Lenz * has published a record of the readings for every hour of the day and night during 1905. Fortnightly records are sent to all mine-surveyors in this district. The maximum amplitude, or difference between the highest and lowest readings, during the year, was 43·1 minutes on November 12th, and the least amplitude was 3·5 minutes on December 16th.

Mr. H. Gannett † has collected all the data available regarding magnetic declination in the United States, with a view to meet the needs of those who have occasion to use the magnetic-needle in surveying, or have to deal with surveys that have been run with the needle in past times. The results are presented in the form of tables, showing the approximate reduction to the year 1900, the declination being given in the tables by counties, cities, and towns. Tables of magnetic declination in the United States for 1902 have been drawn up for the Coast and Geodetic Survey by Mr. L. A. Bauer.

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* *Glückauf*, vol. xlii., 1906, p. 284.

† *United States Geological Survey, Seventeenth Annual Report*, 1896, p. 201.

CHAPTER VI.

LOOSE-NEEDLE TRAVERSING.

Instruments Employed.—The measurement of directions in this method of surveying necessitates the use of only simple forms of instruments, two types of which will be considered in the present chapter—viz., the miner's dial and the "prismatic compass," the principal use for which may be said to be the measuring of directions of lines with reference to the magnetic meridian. The German dial or hanging compass is used exclusively for loose-needle traversing, but the method of procedure adopted for its application being quite distinct from that when the other types of instrument mentioned are used, it is treated of in a separate chapter. The vernier dial, which is described later, is also used extensively for loose-needle traversing, and the method of using it for the purpose of measuring magnetic bearings is identical with that employed with the simple miner's dial.

Historical Sketch.—Although the use of the magnetic-needle by mariners is described in a French poem of the year 1190, the credit of having first enclosed a magnetic-needle in a box is usually assigned to Flavio Gioja (1302-1320). The use of the magnetic-needle for surveying mines is described by Georgius Agricola in the fifth book of his *De re Metallica*, published in 1556. The compass there described is of a very primitive character. It consists of a series of seven concentric circles filled with wax of different colours: in the middle is a depressed receptacle to contain the magnetic-needle. An old compass of this type is preserved in the collection of the School of Mines of Clausthal in the Harz. It bears the date 1541, and consists of a wooden plate, ¾ inch thick and 6½ inches in diameter, in the middle of which is a small brass compass-box, 2 inches in diameter. The whole is placed in a circular receptacle in a wooden box, which may be closed by a lid, and which is provided with a hole in its base, probably to enable it to be placed on a stand. The compass has only a north and south line marked, and round its raised edge a double ruler revolves. The wooden ruler has several concentric circular depressions, filled with wax of different colours. When in use, the instrument was so placed that the needle pointed to the north, and the ruler revolved until it pointed in the direction, the bearing of which was required. A scratch was then made on one of the wax circles to indicate this direction. The laying down of the results was effected by repeating the survey at the surface, commencing at the mouth of the shaft. The object of such surveys was merely to determine how near the underground workings were to the boundary of the concession.

In the 17th century, mines were surveyed in this country in a somewhat similar manner. Thomas Houghton, writing in 1681, describes the method of surveying adopted in the Derbyshire mines, as follows :—" Having provided yourself of a *Dial* in a square Box, or a long square Box, which is better ; and also of a Two Foot Rule, and a String or Cord with a Plummet at the End : first plum the Shaft : Now suppose you come to take a Length forwards into the Drift at the Shaft Foot, having first made a Mark there where the Plum fell, let a Boy hold one End of the String therein, and bid another Man take the Plummet, and go as far back into the Drift as he can, till the Plum he hath in his Hand touches the Side ; and stretching the String streight, observe that it touches no where betwixt that End he holds in the Mark, and the Plummet the other Man hath in his Hand, (if it touches the Side bid him come nearer) then apply the *Dial* to the Side of the String, and when the String and *Dial* lie exactly streight together, take the Point the Needle stands on, which suppose here to be 44 ; set down the Point, bid him make a mark at the Plummet ; then pull back the String and measure it, which suppose here to be 12 rules and 14 inches : Then go to the Mark he hath made, hold one End of the String in it, bid him go back into the Drift with the Plummet as far as he can, till the middle of the String begins to touch the Side ; then stretching the String streight, observe that it touches no where betwixt them that hold it, apply the *Dial* to the Side of it, and take the Point the needle stands on."

The process was then repeated until the end of the level was arrived at. The lengths and bearings thus obtained were pegged out at the surface, and thus a mark was obtained above ground exactly above that left at the end of the level underground. "You must observe," says Houghton, "that your Rule and String lie parallel with the Edge of your Dial, that is, equally at both Ends ; or else you will miss in taking the true Point.

Under Ground the Dial is guided by the String; but above Ground the String is guided by the *Dial.*"

Even in the middle of the 18th century, dialling was carried on with appliances of a very primitive character. "The instruments used," writes Dr. W. Pryce in 1778, "are, a compass without a gnomon or style, but a center pin projecting from the middle of the compass to loop a line to, or stick a candle upon, fixed in a box exactly true and level with its surface, about 6, 8, or 9 inches square, nicely glazed with strong white glass, and a cover suitable to it hung square and level with the upper part of the instrument: a twenty-four inch gauge or two-foot rule, and a string or small cord with a plummet at the end of it: a little stool, to place the dial horizontally: and pegs and pins of wood, a piece of chalk, and pen, ink, and paper."

The author warns "those who take no account of the points or angles of the compass, but in lieu thereof, chalk the bearing of the line they measure with, on the board the compass lies in; for if they are not exceedingly careful and precise in their operations, they may commit almost unpardonable and irretrievable blunders: yet formerly, before penmanship and figures were so generally understood and practised among the common Tinners, as they are at present, most of our Mines and Adits were dialled for in this manner."

Towards the end of the 18th century, the dial was fitted with sights, by means of which the direction of the station-line could be taken with precision.

Construction of the Miner's Dial.—A simple form of the instrument is shown in Figs. 13 and 14, the former representing its general appearance, the latter being a section through the centre of the compass-box. It consists of a brass box mounted so that when in use it can be rotated in a horizontal plane. Inside the box is a brass ring graduated on its upper face. At the centre of the graduated ring a vertical steel pin is securely fixed, on which a magnetic-needle is freely suspended. The needle is protected by a glass cover, and usually a brass cover is provided in addition, for the protection of the glass when the instrument is not in use. A line passing through the zero of the graduations and the centre of the steel point carrying the needle forms the centre line of the instrument, and exactly in this line are two folding sight-vanes rigidly fixed on an extension at either side of the box. The sight-vanes consist of two stout strips of metal, in which "windows" and "slits" are cut. A window being a comparatively wide opening across the centre of which a piece of horse-hair, preferably white, is stretched; this being fixed by means of small wooden pegs driven with the ends of the hair into holes bored above and below the centre of each window. The correct position of the hairs is defined by two fine notches.

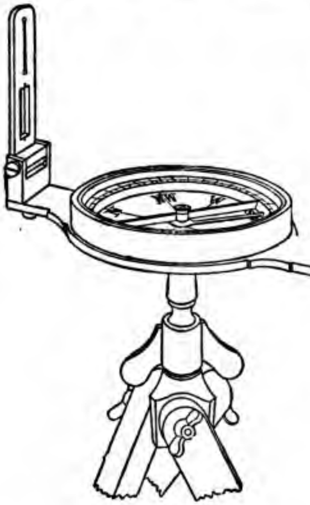


Fig. 13.

The slits are simply fine cuts through the metal, which is cut away in the region of the slit to present thin edges. On one of the vanes a window is uppermost, and on the other a slit, so that the operation of lining through can be performed from either sight. For the instrument to be in correct adjustment it is essential that the slits and cross-hairs all lie in a plane passing through the centre line of the instrument and perpendicular to the graduated face of the compass ring. The sight vane adjacent to the zero

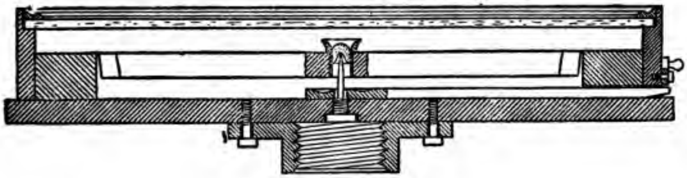


Fig. 14.

of the graduations is spoken of as the north sight, and the other as the south sight.

Graduated Circle.—The graduation of the miner's dial does not correspond with that on the imaginary horizontal circle previously defined (p. 62), but progresses in an anti-clockwise direction; this system being adopted so that the reading obtained, when taking an observation, by noting the position of the north-seeking end of the needle with reference to the divided circle, represents the direction of a line according to the usual mode of expressing directions. The necessity for the reversal will be apparent from Fig. 15, which represents diagrammatically the position of the needle with reference to the divided circle when measuring the magnetic azimuth of a line AB, which is shown on the left-hand side of the figure to be about 320°. In making the observation the instrument is set up at A, and the line of sights is directed so that the north sight is pointing towards B. The position assumed by the needle is as shown, and it will be evident that if the graduation were clockwise the reading would be about 40°, but if contra-clockwise it would be about 320°, the magnetic azimuth of the line.

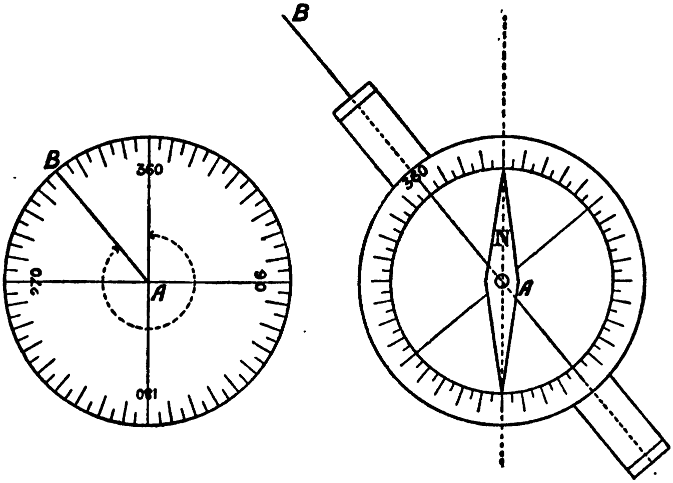


Fig. 15.

An illustration of the necessity of this change may be afforded by imagining a watch in which the dial-plate moves from left to right, whilst the hand remains immovable. It is evident that the hours must count from right to left for the watch to indicate the right time. Similarly, in the case of the miner's dial, the magnetic-needle always points to the north, and may consequently be compared with the fixed hand of the supposed watch.

In addition to the continuous graduation from zero up to 360°, the miner's dial is usually graduated in quadrants on the base of the instrument, divisions of 10° only being shown, the cardinal points being lettered, and the east and west points being transposed to conform with the whole circle graduations.

In some of the earlier types of miner's dials, and in some modern vernier dials, the circle will be found to be graduated in a clockwise direction; the needle readings obtained with such instruments may be plotted with a special protractor, graduated to correspond with the readings, or the readings may be converted into azimuths by subtracting each from 360°.

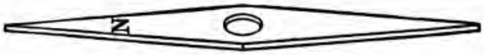


Fig. 16.

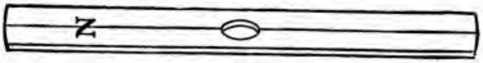


Fig. 17.

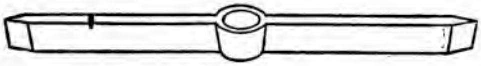


Fig. 18.

The Magnetic-Needle.—In shape the magnetic-needle may be either rhombic (Fig. 16) or rectangular (Fig. 17), or its height may be greater than its breadth (Fig. 18). The first two forms are known as "broad" needles, the latter as an "edge-bar" needle. Edge-bar needles are generally used when the needle itself is used to indicate the readings, as in practically all forms of miner's dial, broad needles being used in surveying instruments when a card or ring is attached to the needle, as in the prismatic compass. The broad needle shown in Fig. 17 has a centre line engraved on it which is used for indicating the readings.

The north-seeking end of the needle is marked by a deep notch on edge-bar needles, or by a brass pin. The latter mode of marking is preferable, being much more noticeable.

The needle is drilled through in the centre, and carries above the aperture a hollow brass cap, lined with some hard stone conically hollowed out. Agate or carnelian is usually employed for the purpose; but ruby, though brittle, is best if carefully treated. The cap must be as light as possible, and it must be firmly fixed to the needle in such a way that its axis forms a right angle with the axis of the needle. The interior of the cap must be accurately conical. Caps made of brass, silver, or steel should be avoided, as they cannot be polished so well as those of agate, and they are very soon bored through by the centre pin. This pin is made of good steel with a hard, smooth, round point, the angle of which is not too great. The more pointed the pin and the more obtusely conical the interior of the cap, the less is the friction of the needle on its pivot.

The needle must be made of hard steel, and so constructed that its geometrical centre line passes exactly through the centre of the cap. It must be sufficiently magnetised, and, when placed on its pivot, must assume a horizontal position. A needle which is horizontal before being magnetised, will dip after having been subjected to that treatment. It is, therefore, necessary to make one end of the needle heavier than the other.

In order to preserve the pin from unnecessary wear, and from being broken off when the instrument is carried, a contrivance is employed for fixing the needle. This consists of a slide, screw, or cam, manipulated from outside, which raises the needle and presses it against the glass lid of the dial. When required to be used, the needle should be lowered carefully, so that it gently rests and does not fall upon the centre pin.

Much depends upon the sensitiveness of the needle. A sluggish needle is utterly useless. The needle may be tested by bringing a piece of iron near it when at rest, observing whether it returns exactly to its former position after a few oscillations. The test should be made at several points round the dial. The needle should not move when the dial is gently revolved.

All parts of the dial, with the exception of the magnetic-needle and the centre pin, must be made of metal free from iron or nickel. They may be tested, after removing the needle of the dial, by bringing them near a sensitive magnetic-needle balanced on a centre pin fixed in a piece of wood, and noting whether the needle moves, as each separate portion of the dial is brought near it.

In making a survey with the dial, care must be taken that nothing capable of attracting the needle is carried about the person, such as penknives, keys, steel watch-chains, spectacles, nickel-plated studs, or iron rivets in the magnifier used to read the graduations. Watches in which the movements are made of nickel, attract the needle almost as much as when the movements are made of iron. The brims of felt hats are sometimes stiffened by inserting an iron wire round the edge. The surveyor should therefore examine both his watch and his hat before commencing a survey. Sometimes the needle persistently sticks to the under side of the glass. This is caused by the glass becoming electrified from rubbing against the clothes, or from being cleaned with a silk handkerchief. The electricity may be at once removed by touching the glass with the moistened finger or by breathing on the glass. An unsuspected source of error in magnetic-needle readings has recently been discovered to arise from the magnifying glass used for reading the graduations becoming electrified. The magnifier generally used for that purpose has a hard, highly-polished, black frame, which is peculiarly liable to become electrified, even by the mere carrying in the pocket, so that, when brought near the magnetic-needle, it draws it sometimes as much as half a degree from its true resting place.

In a good dial the centre pin of the needle should be exactly in the centre of the graduated circle, and the needle should be straight. If this is not the case, there will be an error of eccentricity in every observation. The *constant eccentricity*, when the centre pin and the ends of the needle are not in one vertical plane, and the *variable eccentricity*, when the centre pin is eccentric to the graduated circle, may be detected by the readings at the two ends of the needle not agreeing. In both cases the error may be corrected by reading both ends of the needle, and by taking the mean of the two results. Cases of *irregular eccentricity* are sometimes met with—that is, when the point of suspension of the needle in the cap is variable. Needles presenting this error are useless.

The Tripod.—The dial is usually supported on three legs shod at the bottom with metal points and connected at the top in such a way that the legs can be moved to accommodate themselves to an uneven floor, and also enable this instrument to be set at varying heights and yet form a rigid combination. A simple form of tripod is shown in Fig. 13, and is quite effective for light instruments. Another form of tripod frequently used is shown in Fig. 19.

For use in very low workings the legs, which are made circular in section just below their attachment at the top, are jointed, as shown in right-hand of Fig. 19, at about half their length, so that the lower portion of each can be detached when necessary, a set of extra points being provided to screw on to each of the shortened legs.

The dial is connected with the tripod by means of a " ball-and-socket " joint, an old but very effective form of which is shown in Fig. 20.

The top portion of the joint fits into a corresponding socket at the base of the dial, and is kept in position by a screw, the end of which fits into the groove shown at A. By slightly loosening this screw the dial is free to rotate. The connection of the joint to the tripod is made secure by means of the screw at B. The tightness of the actual ball-and-socket joint is controlled by the cross-screw and worm-wheel shown at C. A portion of the socket is cut away, as shown at D, to permit of the dial being turned over at right angles to its normal position, for the purpose of measuring vertical angles.

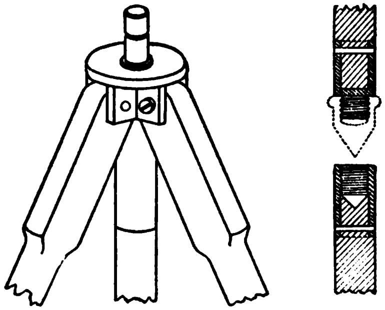


Fig. 19.

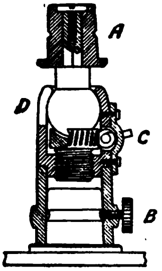


Fig. 20.

Spirit Levels.—On some miner's dials two spirit levels, set at right angles, are let into the base of the compass-box, where they can readily be viewed and yet are protected. These are for the purpose of setting the box in a horizontal plane previous to taking observations. For all purposes to which a simple miner's dial can be applied, the operation of levelling can be sufficiently accurately performed by the aid of the needle itself, the instrument being manipulated through the ball-and-socket joint so that the top edge of the needle is flush throughout with the edge of the graduated ring when the box is turned through a complete revolution.

Spirit levels are universally employed in vernier dials and theodolites, and their construction is dealt with on p. 259.

Underground Surveying with the Miner's Dial.—The general method of using a miner's dial for traversing underground can be best described by detailing the procedure adopted in a simple case such as that illustrated in Fig. 21, which represents a portion of a mine roadway which has been previously surveyed up to the point A, where a mark has been left in the roof. It has been assumed that candles are used for illumination, and that the general precautions necessary to be taken when using the magnetic-needle, and which are detailed on p. 81, have been carefully noted.

The instrument is taken to the bend at B, and the legs of the tripod are spread out and set on the ground so that the head is as nearly as can be judged in the centre of the roadway. The dial is fixed securely to the head of the tripod and the needle is unclamped. The ball-and-socket joint is then adjusted so that the compass-box can be brought into a horizontal position by the application of fair pressure, such as can be exerted by taking hold of the sides of the compass-box by both hands, but the joint must be sufficiently tight to prevent the instrument from being disturbed by a slight accidental touch. The way in which the ends of the needle lie with regard to the edges of the divided ring guides the operator in bringing the dial to a horizontal position, if no spirit levels are provided. The dial being now levelled, it is turned so that the north sight is pointing in the direction of the traverse—*i.e.*, it lies on the side furthest from A. An assistant is now directed to fix a light on the floor exactly under the mark left at A, a lump of clay being very useful for this purpose. The surveyor takes his own light in his left hand, and taking up a convenient position, he holds the light so that it is in front and a little to the side of the south sight, the hair fixed across the window of this sight thus becoming most clearly visible. Putting his eye at one of the pin-holes at the extremities

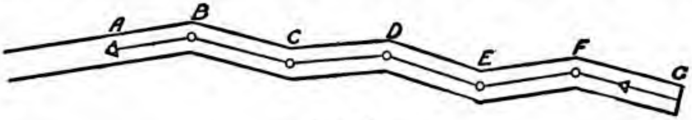


Fig. 21.

of the slit in the north sight, he rotates the dial with his right hand until the signal light fixed at A comes into view through the window of the sight opposite; he then proceeds by gently tapping at the base of one or other of the sights until the hair appears to bisect the signal light. Usually by this time the needle has come to rest, and the reading of the north-seeking end is taken by the surveyor placing himself in line with the needle and noting the intersection of the end with the graduated circle. After taking the reading, he generally satisfies himself that the sighting has been correctly performed by taking another glance through the sights before entering the reading in his notes. He then comes round to the other side of the dial, and proceeding as before, but this time with his eye applied to the south sight, he directs the line of sights on to a light placed at C. When the reading for this line has been booked, the needle is lifted off its centre. The position occupied by the centre of the instrument is obtained by plumbing on to the floor, and the distance from A to B is measured and noted, and then that from B to C. The dial is then taken to the bend at D, and subsequently to F, the operations described being repeated at each of these stations. The signal light fixed at C is not disturbed until it has been observed from D similarly with the signal light placed at E, which is observed from D and F. The dial is thus set up only at alternate stations, the directions of two adjacent lines being observed at each of the stations occupied.

It is important to note that in this method of traversing the north sight of the dial must always point in the direction of the traverse or, as it is sometimes expressed, "leads" the traverse, and the reading of the needle must always be taken at the north end.

It has already been noted that the graduated circle shows quadrant divisions, as well as the whole circle divisions, but confusion is less likely to arise if these are entirely ignored. Mistakes in reading the quadrant letterings are very easily made, especially when the bearings approximate to the cardinal points.

Off-setting Underground.—In surveying underground roadways the traverse is usually conducted so as to follow as closely as possible the centre line of the roadway, which is represented as being of uniform width on the plan. It is convenient, however, in some cases to set the instrument away from the centre, and it is then necessary to take off-sets, so that the roadway can be correctly represented. Off-sets are taken at right angles to one of the lines adjacent to the station, and generally it is only necessary to take them at the stations themselves, these being generally situated at bends. When intermediate off-sets are required, a light placed opposite the point to be off-set should be lined through with the dial, alignment with the chain or tape as performed at the surface being practically impossible.

Reference Marks.—In loose-needle traversing the stations are not usually permanently marked, although it is advisable to mark the position of each in such a way that it can be found again if required within such time as usually elapses before the survey is plotted, so that a check measurement of distance or direction of any particular line can be made if the plotting is not satisfactory. In dry mines a cross surrounded by a circle may be chalked on the roof; in damp mines in which safety lamps are not compulsory satisfactory marks for the purpose can usually be made by smoking the roof with a small candle or lamp flame and making a cross on the smoked surface. Permanent marks must, however, be left in suitable places, from which the survey is subsequently carried forward. A hole drilled in the roof or side to receive a wooden plug forms a good mark. If the mark is not put in exactly on one of the traverse lines, its position must be fixed by off-setting.

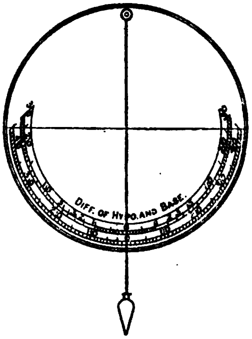


Fig. 22.

Taking Vertical Angles.—In the old type of miner's dial, the brass cover protecting the glass fitted on in one position only. The edge was graduated to 45° on each side of a zero-point, a pin being fixed on the edge directly opposite that point. The line joining the pin and the zero-point was at right angles to the line of sight. Fig. 22 shows the method of graduation. Vertical angles were measured by turning the instrument, by means of its ball-and-socket joint, until it was in a plane at right angles to its proper position for taking horizontal angles, the graduation of the cover being at its lower edge. A plumb-line was then suspended from the pin in the upper edge of the cover. This line coincided with the zero of the graduation when the sights were horizontal. Angles of slope were then measured by sighting a light held at a station at the same height from the floor as the centre of the compass-box. On turning the dial in a vertical plane so that the cross-wires bisected the light, the number of degrees indicated by the plumb-line was found to represent the angle of elevation or depression. In addition to the division into degrees, the plate was also divided to show the difference between hypotenuse and base, so that the correction of the distance for slope could be applied at once.

This arrangement for taking vertical angles has been superseded since the invention in 1850 by Mr. John Hedley, H.M. Inspector of Mines, of the arrangement for moving the sights in a vertical plane by means of a rocking centre attached to the compass-box. This arrangement, besides enabling magnetic azimuths to be taken of lines lying at much greater inclinations than was possible with the simple forms of dial available before, also permits of the provision of a divided vertical arc or circle for measuring the inclinations with the compass-box in its normal position, such measurements being also obtained much more rapidly. Hedley's arrangement, as supplied on a simple

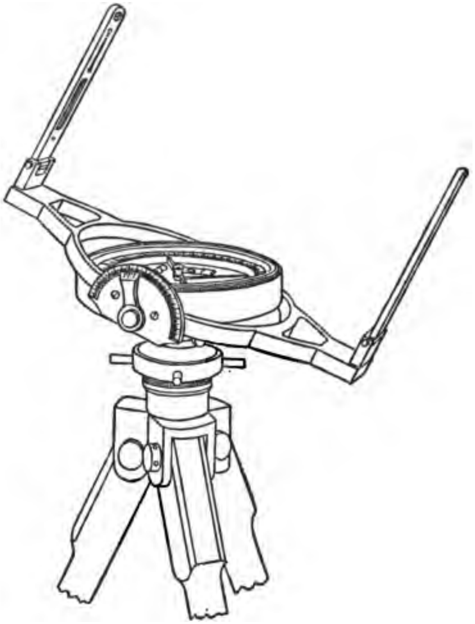


Fig. 23.

form of vernier dial by W. F. Stanley & Co., London, is shown in Fig. 23. In this case an arm carrying a vernier is attached to the rocking centre, and this may be said to be rigid to the compass-box. A divided semicircle is rigidly attached to the frame carrying the sights, so that the vernier records the inclination of the frame. In measuring vertical angles with this dial, a light fixed at a station at the same height above the floor as the line of sight of the dial is sighted with a special pair of sights, consisting on one side of a pin-hole, and on the other of a circular window with horse-hairs arranged in the form of a cross, the horizontal hair being brought into coincidence with the light.

Other arrangements for measuring vertical angles are described in Chapter IX.

Field Book.—Unfortunately, there is no standard practice with regard to the form of entry for notes of underground surveys, and the systems adopted at different mining centres are often quite diverse, as will be seen from the various examples given in this book. Various modifications of the system used for chain-surveying at the surface are used, and entry in the form of a complete sketch of a mine or portion of a mine is favoured in many districts. Entry in columns is adopted to a great extent in the surveying of metalliferous mines, and where no off-sets are taken is quite satisfactory.

An example of entry in columns is given below.

WORK AND REST MINE.—ADIT LEVEL.

From perpendicular line in engine shaft 3/- W. and 2/- N. of centre.
Shaft (90°) 14 by 7.

No.	Bearing.	Distance.			Offsets.		Remarks.
		fms.	ft.	ins.	R.	L.	
A	359° 45′	12	2	6	2/-	3/-	
B	346° 00′	13	4	10	3/6	2/9	
C	332° 21′	10	3	0	2/-	3/-	N. 2/6 S. 3/-
D	275° 03′	5	0	2	4/-	5/-	
E	254° 06′	3	5	9	6/6	3/-	
F	292° 15′	32	0	0	4/2	6/-	
G^2	184° 00′	12	0	0	3/-	3/-	END of × cut.
G	272° 00′	16	0	6	3/9	3/9	
H	264° 06′	5	4	0	2/6	2/-	
J *	232° 00′	3	5	9	2/-	2/6	Peg and nail, N. wall, 2/- N. of J.
K	232° 00′	1	0	0	2/6	2/6	END.

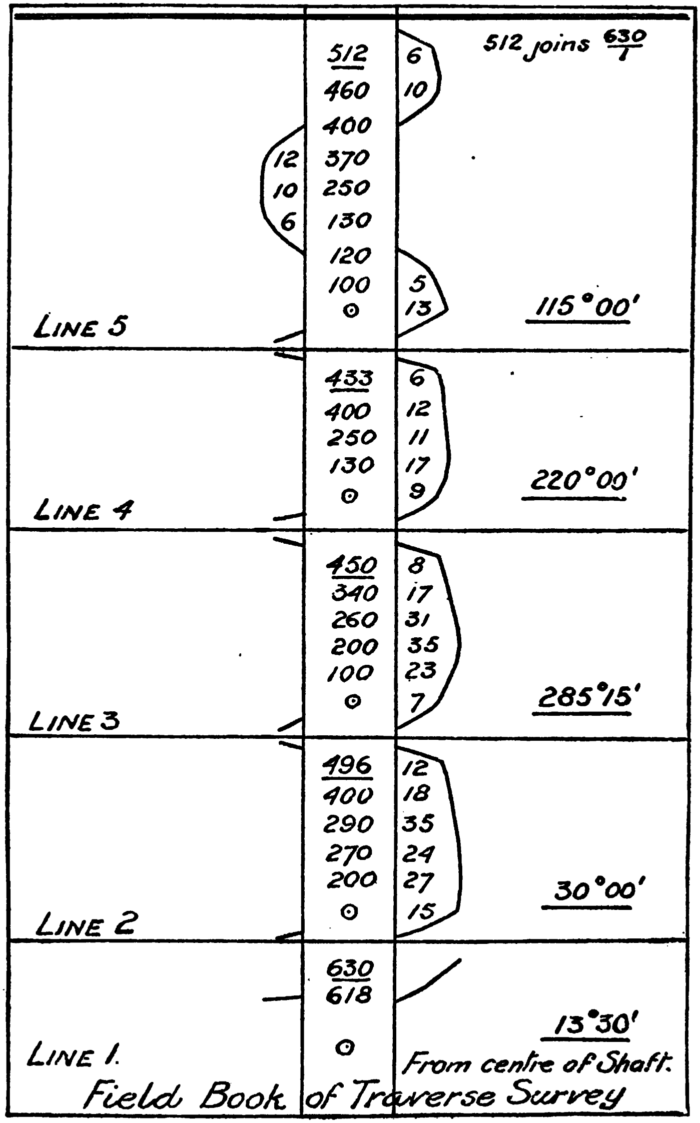
The above are the notes of the survey of the adit level of a supposed metalliferous mine, the name of which was suggested by Mr. J. Henderson, M.Inst.C.E., as showing the intermittent nature of many metalliferous mines, which are so frequently abandoned when the metal falls in price, and re-opened in better times.

The survey is made in the adit level, and starts from a perpendicular line in the vertical engine shaft, which is rectangular in section, 14 feet long by 7 feet wide. The dial is set up at A, and an observation is taken to the perpendicular line, the observer looking through the north sight of the instrument. The bearing indicated by the north-seeking end of the needle is read and entered as the first bearing. It will be found advisable to write the degrees and minutes as if the latter were decimals; in this way any confusion between such numbers as 30′ and 3′ is avoided. The length of the station-line is measured, and the result, 12 fathoms 2 feet 6 inches, entered in the distance column.

The offsets are measured in feet and inches, and, in order to necessitate as little writing as possible—an important matter in a wet mine—may be written in a way similar to the abbreviated mode of writing shillings and pence.

At C the survey line leaves the cross-cut driven from the shaft to the lode, and continues on the lode. As there is a sharp turn at this point, offsets are measured to the north and south, as well as to the right and left. At F a cross-cut is driven south of the lode. The dial being set up at F, an observation is taken to a candle at the end of the cross-cut. The bearing is then read, and the distance, 12 fathoms, measured. This line is a branch from the main survey line, and is distinguished by a small figure 2 attached to the letter that would have been assigned to the station had it belonged to the main line. With the dial still at F, an observation is next taken to G, and the survey continued as before. At K, the *end*, or *fore-breast*, is reached, and a permanent mark has to be left, from which the survey may be continued at a future date.

Surface-Surveys with the Miner's Dial.—For making the surface-surveys, the dial may be used in much the same manner as it is underground. There is, however, the advantage that opportunities frequently occur of checking the work during its progress by means of tie-lines. It is not usual, though occasionally advantageous, to carry out surface-surveys at night; under these circumstances, the operations are conducted exactly as if they were being done underground. In the daytime ranging rods are used as signals instead of lights. In surface-surveys



	512	6	512 joins $\frac{630}{1}$
	460	10	
	400		
12	370		
10	250		
6	130		
	120		
	100	5	
	⊙	13	115°00'
LINE 5			
	433	6	
	400	12	
	250	11	
	130	17	
	⊙	9	220°00'
LINE 4			
	450	8	
	340	17	
	260	31	
	200	35	
	100	23	
	⊙	7	285°15'
LINE 3			
	496	12	
	400	18	
	290	35	
	270	24	
	200	27	
	⊙	15	30°00'
LINE 2			
	630		
	618		
			13°30'
LINE 1.	⊙	From centre of Shaft.	

Field Book of Traverse Survey

the measurement of distances and off-setting are performed as in chain-surveying and the form of field book usually adopted is very similar, a simple example, which is the record of a survey of a four-sided field connected with the shaft of a mine, is given herewith. The starting point of the first line is the centre of the shaft, and all the distances are given in links.

As a rule, in traverse-surveying, the starting point of a line is the finishing point of the previous line, so that there is no necessity to note specially the starting and finishing points of each line, as in the field book of chain-surveys. It is only where more than one line runs from the same station, as occurs—*e.g.*, at junctions of roads—that the starting points of such lines require to be particularly noted.

Prismatic Compass.—This instrument, which is shown in Figs. 24 and 25, consists of a glass-covered circular brass box made in sizes from 2½ up to 6 inches in diameter, containing a magnetic-needle, attached to which is a card or aluminium ring, graduated in degrees in the smaller sizes, and to ½° or ⅓° in the larger. Folding sights are attached to the rim of the box, one of them being as long as a diameter of the box, and carries a fine thread or a thin strip of metal placed edgewise; the other sight, which is shorter, has a slit in its upper part, and carries a reflecting magnifying prism, which can be so placed that, on looking through the slit, the vertical thread of the opposite sight appears as a line over the graduations on the card or ring,

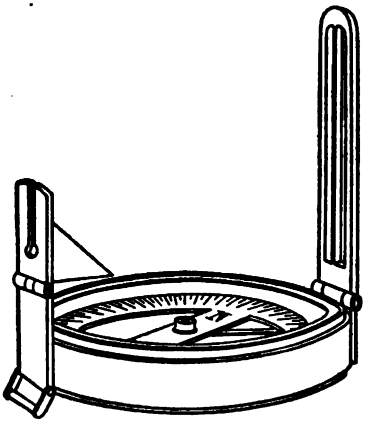


Fig. 24.

the thread and the graduations being visible to the eye at the same time, the graduations being so arranged that the reading of the thread gives the magnetic azimuth of the line of sight. A spring pin is placed under the long sight (see Fig. 25) for the purpose of damping the oscillations of the needle. The zero of the graduations is at the south-seeking end of the needle. In taking observations with this instrument in a direction reverse to that of the traverse the readings obtained differ from the normal direction by 180°, and must be corrected accordingly.

As the sighting of an object and the reading of its direction are both done at the same time, the instrument can be used in the hand, and this forms one of its principal features, as observations can be taken when walking or riding, or from practically any conveyance. When used in the hand, the readings may be obtained to within 30 minutes to 2 degrees. By mounting the compass on a stand, results comparable with those given by the miner's dial can be obtained. Its principal use may be said to be for military purposes, for which it is extensively employed, but as a mine-surveyor engaged in prospecting work is often

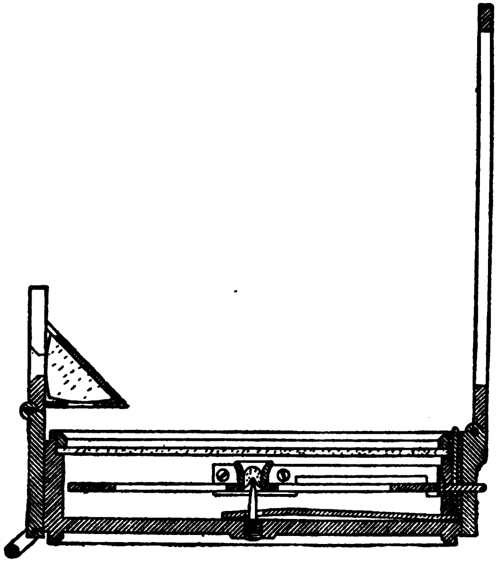


Fig. 25.

called upon to make plans of a similar nature to those required in military work, he should be familiar with the prismatic compass and the mode of using it.

The distance of the traverse lines is measured in various ways, such as pacing, or by the time taken to pass over the distance when travelling at a measured or estimated rate either on horseback, or in a carriage, or in a water-borne conveyance. As an instance of the adaptability of the prismatic compass in making approximate surveys, it may be mentioned that traverses were made in South Africa before the Boer war by travelling in a waggon and noting the number of revolutions of a wheel, approximate forward bearings being taken with the compass at intervals.

The method of making a traverse with the prismatic compass can be illustrated by describing the procedure in the case of a winding path through a wood. At the beginning of the path the instrument is taken from its case, and the sights folded back into their working positions, the needle being automatically let down on to its centre when the longer sight is turned up. Holding the instrument as nearly level as he can judge, the surveyor looks through the slit at the prism sight, and turns the compass round in his hand until the thread on the forward sight bisects the path at the furthest point at which it is visible. He notes the mean reading of the thread. He then folds up the long sight and paces forward to the point he has sighted to, on noting which he takes another forward bearing as before, and books the new bearing, and then paces forward. He proceeds thus until the end of the path is reached. The notes in a survey of this nature could be entered in two columns. When a number of features are being surveyed a modification of the field book for chain-surveys is a most satisfactory method of entry. Such a survey as described could be plotted by any of the methods used for plotting traverse-surveys after the distance corresponding to the paces had been ascertained.

The prismatic compass is used in filling in details in triangulation surveys, but, being generally used on a tripod for this purpose, presents no advantages over the miner's dial.

Modifications of Prismatic Compass.—Various modifications have been introduced with a view to increasing its field of use; thus, attempts have been made to render it applicable to underground surveying where the difficulty of lighting generally prevents its use. None of these, however, have been adopted to an appreciable extent. Again, the ordinary form of prismatic compass cannot be used for measuring vertical angles, and various combinations of clinometer and prismatic compass have been introduced.

Brunton Pocket Transit.—This instrument, which was patented by Mr. D. W. Brunton in 1894, consists essentially of a compass with folding sights, one of which is found in the centre of a mirror, which latter enables the compass readings and those of a vernier attached to an arc used for taking vertical angles, to be observed at the time sighting is being effected.

Verschoyle Pocket Transit.*—In this instrument the prism and folding sight are placed on one side of the compass-box, and a spirit level and arc for measuring vertical angles are incorporated in its construction.

Testing of Prismatic Compasses.—In a paper by F. E. Smith,† A.R.C.Sc., very valuable information is given of the errors to which the prismatic compass is liable, and many of the remarks apply to any instrument in which a magnetic needle is used.

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* *Trans. Inst. Min. Eng.*, vol. xxxii., p. 165.

† On the Manufacture and Testing of Prismatic Compasses, especially Mark VII., Military Pattern." Reprinted from the *Transactions of the Optical Society*, and published by the Society at 39 Victoria Street, Westminster, S.W., 1916.

CHAPTER VII.

Local Variations of the Magnetic-Needle.

Influence of Iron Rails.—The method of surveying described in the preceding chapter cannot be used in mines where magnetic substances deflect the needle. On account of the increasing use of iron and steel in mines in the form of rails, props, etc., the number of mines in which the magnetic-needle is not affected is extremely small.

Rails placed end to end on the ground become, in the course of time, permanently magnetised, and if a magnetic-needle is brought near the junction of two rails, it assumes a position parallel to the two rails. Some interesting experiments to determine the influence of iron rails on the magnetic-needle were made by Professor Combes of the Paris School of Mines. He found that the nearer the direction of the rails approached that of the magnetic meridian the more highly polarised they became. The following deflections were observed when a miner's compass was brought near rails which were placed in the direction of the magnetic meridian :—

Distance from the Rails.	Height above the Rails.	Azimuth Observed.
	Inches.	
19 ft. 8 ins. on one side,	58	80° 00′
5 ft. 3 ins. on one side,	47	83° 30′
Above the first rail,	43	83° 15′
Between the two rails,	43	83° 30′
Above the second rail,	43	83° 45′
6 ft. 6 ins. on the other side,	43	83° 30′

With the rails placed at right angles to the magnetic meridian, the following angles were obtained :—

13 feet 1 inch on one side,	329° 45′
Above the first rail,	328° 00′
Between the two rails,	330° 00′
1 foot 10 inches on the other side,	328° 30′

When the compass was only 15 inches above the rails, deviations amounting to 7° 30′ were observed.

Experiments made at Freiberg, in Saxony, by Professor Junge confirm these results, and permit the following conclusions to be drawn:—

1. Iron rails identical as regards weight and dimensions may act differently on the compass, the deviation caused by one being sometimes double that by another. The influence of two parallel rails on the magnetic-needle cannot be neutralised. It is not sufficient, as so many miners imagine, to place the dial exactly midway between the two rails.
2. The influence of the rails on the needle is increased by sharp blows. Four blows on a rail with a hammer was found to increase by 2° the deviation produced.
3. The influence of the rails is greatest when they form an angle of 45° to 67° 30′ with the meridian. The deviation then decreases until the rail is at right angles with the meridian, when the deviation is intermediate between the maximum and that observed when the rails make an angle of 22° 30′ with the meridian.
4. The influence is very considerable when the compass is as much as 47 inches above the rails. In such a case with rails at an angle of 45° with the meridian, deviations amounting to 3° 25′ have been observed.

No experiments appear to have been made with iron or steel sleepers. There can, however, be no doubt that their influence on the magnetic-needle is at least as considerable as that of iron rails.

The practical conclusion that can be drawn from the results obtained by Professors Combes and Junge, is that an accurate survey cannot be made with the miner's dial in the manner described in the preceding chapter, unless the rails are taken up.

Local Attraction in the Mine.—In many metalliferous mines, local attraction, due to the presence of magnetic iron ore in the lode, is very considerable. At Botallack mine, in Cornwall, for example, the needle has been known to be deflected to the extent of 60° from its proper bearing. Experience shows that certain eruptive rocks, notably those of a dark colour with a base of hornblende or augite, affect the needle in the same way as magnetite or magnetic pyrites. In districts composed of magnetic rocks, the dial cannot be employed, as is shown by observations made at Ammeberg in Sweden, where at equidistant points along a straight line, the following bearings were obtained:—3° 5¾′, 3° 4′, 3° 2½′, 3° 1′, 2° 7¾′, and 2° 6′. To make a number of observations along a straight line is the best method of finding out if there is any local attraction affecting the needle. The influence of magnetic deposits on the compass has been utilised in Sweden and the United States in exploring for iron ore.

Surveying with the Dial in the presence of Iron.—With the general employment of iron rails in mines, the question arises to what extent may surveys be made with the ordinary dial without fear of deflections of the needle giving rise to error? As a matter of fact, the magnetic-needle may be used for the purpose of obtaining the true bearings of the traverse lines in places where attraction exists, provided that the mode of procedure is slightly modified. The method is based upon the fact that the deviation of a magnetic-needle remains the same, if the relative positions of the dial and the attracting object remain unaltered. All that is necessary is to note the back- and fore-bearing at each station, however much the magnetic-needle may be deflected. Then, if the needle is attracted on looking to the back object, it is attracted to precisely the same extent on looking forward, so that the difference of bearing of the two lines is unaltered. Consequently, if a correct bearing of any one line of the traverse can be obtained, an accurate survey may be made. This method of traversing, however, is not recommended for general practice, fixed-needle dialling with the vernier dial being far preferable. It should also be noted that the precautions with regard to articles of iron about the person of the surveyor must be taken, as in the method previously described, and even more scrupulously (see p. 81).

Dialling-Book.—The best form of dialling-book to adopt is an ordinary account-book, the £, s., and d. columns serving for fathoms, feet, and inches. If the measurements are made in links, only one column is required. The date column of the account-book serves for the number of the draft. In the space between the date and money columns, two lines are ruled, giving three columns, which may be used for the back-bearing, the fore-bearing, and the calculated true bearing.

The method of booking a survey is shown by the following example of a closed traverse, surveyed in the presence of a very large amount of iron. The bearings and distances were as follows:—

No.	Back-Bearing.	Fore-Bearing.	Correct Bearing.	Fms.	Ft.	In.
A	..	3° 36′	3° 36′	6	4	1
B	3° 36′	1° 36′	1° 36′	3	4	10½
C	5° 27′	327° 44′	323° 53′	5	3	5½
D	319° 15′	224° 53′	229° 31′	6	1	7½
E	202° 57′	156° 44′	183° 18′	6	0	1½
F	167° 48′	165° 03′	180° 33′	4	1	8
G	166° 15′	79° 48′	94° 06′	8	0	3
H	79° 34′	349° 04′	3° 36′	..	..	..

The instrument was set up at B, where there was no attraction, and a back-bearing was taken. This was found to be 3° 36′. This bearing being correct, it was also entered as a fore-bearing at A. A fore-bearing was then taken at B; this was found to be 1° 36′. This also is correct, as there was no attraction when the back-bearing was taken, and the dial was not moved to take the fore-bearing. The instrument was then moved to C, and a back-bearing to B taken. This should have read 1° 36′, the correct fore-bearing from B to C. It was, however, found to be 5° 27′, showing that the needle was considerably deflected from its true position. Back- and fore-bearings were taken at each of the following stations, and in each case the needle was found to be seriously deflected. Consequently, before the survey could be plotted, the correct bearings had to be calculated.

The bearings 3° 36′ and 1° 36′, being known to be correct, might be inserted in the correct-bearing column. The back-bearing at C was found to be 5° 27′ instead of 1° 36′. It was therefore 3° 51′ too great, and as the dial was not moved, the attraction remained the same, so that the fore-bearing at C was also 3° 51′ too large. The correct fore-bearing at C, then, was 327° 44′ − 3° 51′ = 323° 53′. The back-bearing at D, which should be the same as this, was found to be 319° 15′—that is, 4° 38′ too small. The fore-bearing taken at the same station under the influence of the same attraction must also have been 4° 38′ too small, so that its correct value is 224° 53′ + 4° 38′ = 229° 31′. The back-bearing at E should be identical with this. It was, however, found to be 202° 57′—that is, 26° 34′ too small. The fore-bearing at the same station must also be 26° 34′ too small. Its correct value, then, is 156° 44′ + 26° 34′ = 183° 18′ This should be identical with the back-bearing at F, which was found to be 167° 48′, or 15° 30′ too small. The fore-bearing at

F is also 15° 30′ too small, and its correct value is 165° 03′ + 15° 30′ = 180° 33′. This should be identical with the back-bearing at G, which was found to be 166° 15′, or 14° 18′ too small. The fore-bearing is also 14° 18′ too small, and therefore the correct bearing is 79° 48′ + 14° 18′ = 94° 06′. This should be identical with the bearing at the last station, which was found to be 79° 34′, or 14° 32′ too small. The fore-bearing at the same station is also 14° 32′ too small, and therefore its correct value is 349° 04′ + 14° 32′ = 363° 36′—that is, 3° 36′. The last line of this traverse is identical with the first, so that the first and last bearings should be identical. Thus, in a closed traverse the surveyor is able to check the accuracy of his work.

The following page from the dialling-book at a metalliferous mine may also be taken as an example for calculation :—

No.	Back-Bearing.	Fore-Bearing.	Time-Bearing.	Fms.	Ft.	Ins.
A	..	245° 12′	245° 12′	9	3	6
B	245° 12′	254° 30′	254° 30′	8	5	6
C	254° 30′	164° 45′	164° 45′	9	5	8
D	164° 06′	169° 24′	170° 03′	4	0	9
E	178° 12′	161° 00′	152° 51′	5	0	8
F	157° 45′	174° 00′	169° 06′	4	1	0
G	171° 27′	186° 42′	184° 21′	4	4	6
H	183° 39′	178° 18′	179° 00′	5	4	9
J	177° 33′	221° 00′	222° 27′	8	2	7
K	221° 00′	79° 18′	80° 45′	1	5	7
L	89° 33′	80° 00′	71° 12′	2	1	5
M	71° 12′	82° 48′	82° 48′	5	3	0
N	82° 48′	84° 24′	84° 24′	3	5	1
O	84° 24′	90° 06′	90° 06′	7	5	2
P	90° 06′	91° 30′	91° 30′	2	5	3

If the first and last bearings are not identical, and if the difference does not amount to more than a few minutes, the slight error, due possibly to the imperfections of the instrument employed, may be to a great extent eliminated by dividing the error by the number of station-lines, and adding the result to, or subtracting it from, each bearing. Thus, in the first example given, if the observed fore-bearing at H had been 349° 00′ instead of 349° 04′, the final error would have been 4′. It would be assumed that no error occurred in reading the first bearing. The error in each bearing would consequently be about ½′, and the calculated bearings could have been corrected for this error by adding ½′ in each case—that is to say, ½′ to the calculated bearing of B, 1′ to that of C, 1½′ to D, 2′ to E, 2½′ to F, 3′ to G, and 4′ to H.

In applying this method to colliery and surface-surveys, it will be found advisable to book upwards in the usual manner, noting the back-observation (B.O.) at each station. A tabulated statement of the bearings may then be made, and the true bearings calculated.

Errors in Compass Surveys.—In all cases where the dial is used for surveying in the presence of iron, the greatest care must be taken in making the observations; otherwise very serious errors may arise, especially in long traverses. This may be illustrated by an example.

In making a survey in the ordinary way with the dial, any error in the readings will cause the next draft to have a false position when plotted. Assuming that a survey is made between the points A and E, Fig. 26, and that the bearings are read direct from the dial without error, the plan of the traverse will be correct, as shown by the line ABCDE in the figure. If, on the other hand, a mistake is made during the progress of the survey, and the bearing, NAB, of the line AB incorrectly determined to the extent of the angle BAB′ or *a*, then the following drafts will have the same error. B′ will be the end point of the first draft when plotted, thus giving a lateral error of BB′. The other bearings of the traverse being correctly determined, on plotting, the lines B′C′, C′D′, D′E′ will be obtained. These lines must be equal and parallel to the lines BC, CD, DE, and therefore BB′ = CC′ = DD′ = EE′. In other words, the lateral error BB′ caused by the incorrect determination of the bearing of the line AB is carried uniformly throughout the traverse, whatever its length

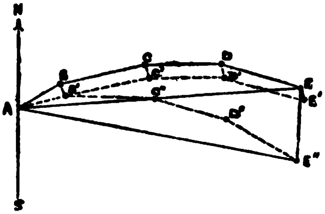

Fig. 26.

may be. The magnitude of this error is found by trigonometry to be $2AB \cdot \sin\frac{a}{2}$.

The magnitude of the error is entirely different when the dial is used as an angle-measurer in surveying over iron. Again, assuming that the bearing of the line AB has been incorrectly determined to the extent of the angle a, the angle NAB′ having been read instead of the angle NAB, if now the dial is employed for measuring the angles, the bearing of the next line, BC, is obtained by adding or subtracting the exterior angle at B, according as the line BC is to the right or left of AB. The other bearings in the presence of iron may be assumed to have been correctly taken. The bearing of the line AB being incorrect, the bearing of the line BC will also be incorrect to the extent of the angle a. Each of the following bearings will be incorrect to the extent of the same angle, so that on plotting the calculated bearings, the line AB′C″D″E″ will be obtained. The error a thus affects the whole traverse from A to E, and increases in proportion to the distance apart of those points. The length from A to E being represented by L, the lateral error, EE″ is equal to $2L \sin\frac{a}{2}$.

It is thus evident that a survey may be very inaccurate, when the angles are not correctly measured. In applying the method of surveying with the needle over iron, the surveyor should not fail to make a check-survey, or reverse course of dialling, selecting fresh points for his stations. Not only in this method, but in all other surveying operations, it is highly desirable that the mine-surveyor should adopt the practice of always checking and verifying every part of his work.*

The Action of Electric Currents on the Magnetic-Needle.—In view of the rapid increase in the number of electric tramways in the Westphalian coalfield and in the use of electric power underground, the question of the action of electric currents on magnetic mine-surveying instruments is of such great interest that Mr. W. Lenz has been induced to conduct a series of experiments. A point, underground, was selected at a horizontal distance of some 100 yards from the rails of the Bochum-Herne electric tramway, and 1,420 feet below it. There, by means of a Fennel's magnetometer with quartz fibre suspension, a series of observations of variation was made based on a fixed line. The magnetometer was previously compared for a long period with the apparatus in the Bochum Town Park, and the two instruments were found to coincide almost exactly. The first observation, in September, 1895, was made by day, the second by night, when the line was free from current, and the last again by day. Whilst the curve of the day-results exhibited great irregularities, that of the night-results was perfectly regular, and in accord with the magnetic records. The irregularities in quite small intervals of time amounted to 2·7 minutes to 5·4 minutes. As at first it was thought that the deviations might be ascribed to the iron-free safety lamps employed, a third observation was made in the morning, the lighting being effected by a stearine candle. The results were exactly the same as on the first day. As the observations were made at a comparatively large distance from other workings, and as the shaft was 200 yards away, it is evident that magnetic observations can, under such conditions, be only satisfactorily conducted during the night in the absence of the electric current. Another source of error is the safety lamp. Composed of various metals, the lamp in a hot condition sets up thermo-electric currents which act on the magnetic-needle. In order to obtain information on this point, the author placed six mine-surveyors' safety lamps free from iron, one at a time, first in a cold condition, then heated, at the pole of a sensitive magnetometer. Of the six lamps examined, two, when cold, had no action on the needle, whilst all acted on it when hot. The deviations observed amounted to from 30 seconds to 160 seconds. A new benzene lamp, that had not previously been used, caused a deviation of as much as 5 minutes. The deviation increased with the temperature of the lamp. A quite new aluminium safety lamp caused the same deviation when cold as when hot. From these results, it follows that the mine-surveyor, before making magnetic observations with delicate instruments, should carefully test his lamp. The influence of slight magnetic properties may be lessened by holding the light in the prolongation of the magnetic axis.

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* The transmission of errors in traverse surveying is exhaustively dealt with by G. R. Thompson, *Trans. Inst. M.E.*, vol. xxvi., 1903, p. 75.

CHAPTER VIII.

The German Dial.

Invention of the German Dial.—The older continental method of surveying mines consists in suspending a compass and a clinometer to a stretched cord representing the line of sight. The compass and the clinometer are read, and the length of the line measured. In this way, the length, bearing, and inclination of the station-line are determined. Mine-surveys were conducted in the manner described by Agricola until the invention of the German dial, or hanging compass, by Balthasar Roessler, who died at Altenberg, in Saxony, in 1673.

Measuring Station-Lines.—The cord is 50 fathoms long. It is made of hemp, and wound round a wooden reel provided with a handle (Fig. 27). This cord is stretched from station to station. The length of the portion stretched depends, of course, on the distance of the stations apart. It should, however, not exceed 8 fathoms, so as to prevent the formation of a catenary curve. The screws (Fig. 28) to which the cord is fastened are 4 inches in length. They are firmly fixed into the timbering of the level. When the cord is stretched between the two points, the length of the line is measured. For this purpose, the Hungarian surveyors employ a fathom-rod; the Saxon surveyors use a brass 5-fathom chain.

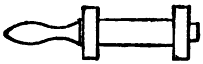

Fig. 27.

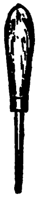

Fig. 28.

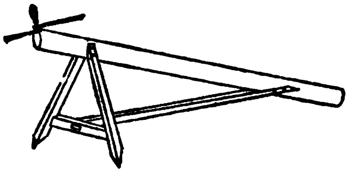

Fig. 29.

For surveys at the surface, or in mines where there is no timbering to hold the screws, a trestle of the form shown in

Fig. 29 is employed. It consists of a beam 8 feet in length and 6 inches in diameter, with two short legs. It should be as heavy as possible, and no iron must be used in its construction.

In the Hartz mines, instead of the cord, a thin brass chain is used. It is 10 metres in length, and is provided with a hook at one end. Every metre is indicated by a brass tag. The chain is wound on a reel, and used in the same way as the cord. The advantages it offers are: 1, It weighs very little; 2, its length can be read without any delay; 3, the best place for hanging the clinometer can easily be found; 4, no further measurements are required to determine the points where offsets have to be taken. Its disadvantage is that it is liable to stretch, and must therefore be carefully examined and adjusted every time it is used.

The Clinometer is used for determining the inclination of the stretched cord. It consists of a thin brass semicircle (Fig. 30), 9 inches in diameter, provided with hooks for hanging it on to the stretched cord. In the centre of the circle is a hole, through which a black human hair is passed, and fastened on the other side by means of wax. At the other end of the hair, a small brass plumb-bob is fastened. The hair touches the graduation of the semicircle, and enables the angle of inclination to be determined. The hooks open towards opposite sides, and are provided with apertures through which a clamp may be inserted when the clinometer is suspended from a highly inclined cord. The graduation begins at the centre of the semicircle—

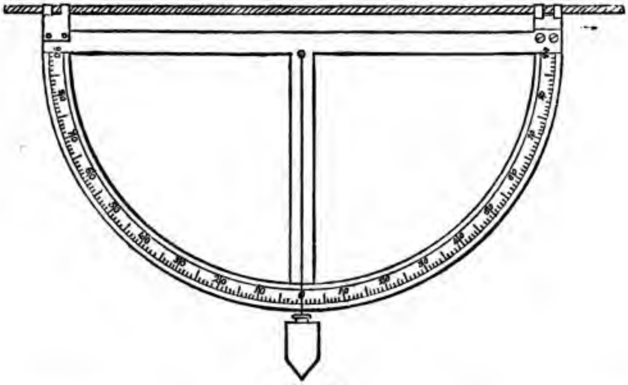

Fig. 30

that is, perpendicularly below the centre from which the plummet hangs. It commences with 0°, and goes to 90° on both sides. Each degree is subdivided into four equal parts, so that an angle can be read direct to 15 minutes. As a rule, the quarter degrees are further divided by the eye into three equal parts, so that angles can be read accurately to 5 minutes. In order to facilitate the reading, the graduated side of the clinometer is usually silver-plated.

Use of the Clinometer.—If a cord, about 10 yards in length, is stretched horizontally, and the clinometer suspended from its centre, the human hair, hanging vertically on account of the weight of the plummet, will coincide with the zero of the graduation, provided that the cord is stretched perfectly tight, and that the clinometer is free from defects of construction. If the cord is inclined at an angle BAC (Fig. 31), the hair will not coincide with zero, but will give the angle DHE, which represents the angle of inclination of the cord. For since AHD + DHE = a right angle, and AHD + BAC = a right angle, AHD + DHE = AHD + BAC, therefore DHE = BAC. The clinometer thus may be used for determining the inclination of lines.

The cord when stretched forms a catenary curve, and consequently the angle of inclination varies at different points in the curve. There must, however, be a point where the cord is parallel to the line joining the two end points, and there the clinometer must be placed in order to obtain the true inclination. The weight of the clinometer being neglected, the correct point of suspension is slightly below the centre of the cord. But the weight of the clinometer alters the inclination of the cord, as it is not uniformly divided between the two hooks. The place where the clinometer must be suspended, in order to give the correct inclination of the cord, has been found by Professor A. von Miller-Hauenfels. His rule is as follows:—The clinometer must be suspended at a certain distance above the centre of the cord. For cords at an inclination of about 15°, this distance is obtained by multiplying the length of the cord by 0·004 for each degree; for greater angles, the length must be multiplied by 0·003 for each degree. Thus, with a cord 12 metres in length inclined at an angle of 20°, the clinometer must be suspended at a distance of 6·72 metres from the lower end. In practice it is found sufficient to suspend the clinometer at the middle of the cord, when the latter is but slightly inclined. With highly inclined cords, however, it is advisable to suspend the clinometer half a yard from the two ends, and to take the mean of the two readings, as the correct angle of inclination. The error will thus not exceed a few minutes in a cord 10 yards in length.

The Hanging-Compass.—The compass-box is 3 to 4 inches in diameter. It is graduated into 360°, or into twice 12 hours. The numbering commences at the ends of the diameter marked north and south, the 12 o'clock line, and proceeds from right to left. At the 6 o'clock line, the east and west points are transposed as in the ordinary miner's dial. In the larger compasses, each hour is divided into 16 parts; in the smaller ones, into 8 parts. Further sub-divisions may be estimated with the eye. The compass is, as a rule, read in hours, eighths, and sixteenths of eighths. One hour is equal to 15°, one-eighth is 1° 15′ 30″, and one-sixteenth of an eighth is 7′ 2″.

In order that the compass shall assume a horizontal position when suspended from the cord, it is constructed on the plan of a ship's compass. When the compass is fastened in the gimbals of the hanging instrument, and suspended from the cord, the 12 o'clock line is in the same vertical plane as the axis of the cord, and the compass hangs level at all times.

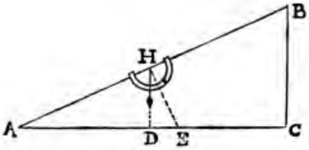

Fig. 31

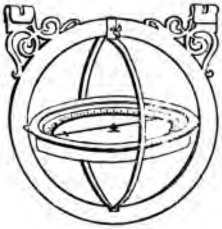

Fig. 32.

The original construction of Rössler's hanging-compass is shown in Fig. 32, copied from Voigtel's *Geometria Subterranea*, the first complete treatise on mine-surveying ever written. It was published in 1686.

An improved form of hanging-compass, made by Osterland of Freiberg, is shown in Figs. 33 and 34.* The hanging ring of the old compass is here replaced by two movable arms. In order to keep the centre of gravity as low as possible, the clamping of the magnetic-needle is effected by a large screw underneath the compass-box.

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* Adapted from Dr. L. Mintrop's "*Markscheidekunde.*"

The compass and clinometer fit into a leather case fastened to a belt worn round the surveyor's waist. A few hairs, some wax, and a plummet must always be carried in reserve.

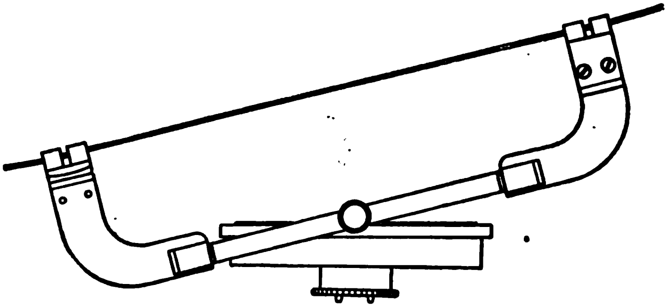

Fig. 33.

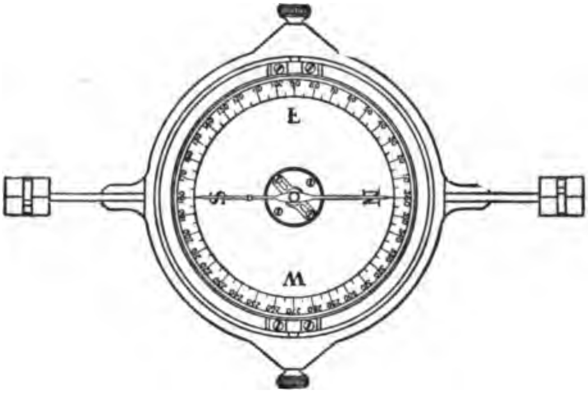

Fig. 34.

Surveying with the German Dial.—In booking a survey made with the German dial, the date, the name of the mine, and a description of the starting-point should first be noted. A fixed point having been selected as a starting-point, intermediate points are so chosen that they can be connected without hindrance by cords 6 to 8 fathoms in length. These points are either in the permanent timbering of the level, or in timbers temporarily inserted for the purpose. At these points, cord-screws are fixed. The loop at the end of the cord is placed over the first screw. The cord is tightly stretched to the next screw, and having been wound round it two or three times, is carried on to the next again. Six to ten station-lines are thus obtained, and the survey is commenced. A plummet is dropped from the first screw to the floor of the level, and the perpendicular distance measured. The length of the stretched cord is measured by placing the measuring rod gently along it. The clinometer is then suspended from the middle of the cord, and the rise or fall read. Lastly, the hanging compass is suspended from the cord near the end-point of the line, care being taken that the north end of the dial is directed towards the end-point of the line. The bearing of the cord is then read. The mode of procedure is the same with the other lines.

The observations are noted in the dialling-book. In the column for remarks, sketches of portions of the level are inserted, showing the position of the offsets measured from the stretched cord. The bearing and dip of any veins or cross-courses met, should also be noted. At the end-point of the survey, a fixed point should, if possible, be selected, and the distance from the floor of the level measured. When great accuracy is required, a reverse survey is made as a check.

When the survey is complete, the bases and perpendiculars of the inclined lines have to be determined. The cord being the hypothenuse of a right-angled triangle, its length must be multiplied by the cosine of the angle of inclination, in order to obtain the base of the triangle—that is, the plotting length of the line, The perpendicular is obtained by multiplying the inclined length by the sine of the angle of inclination.

The form of dialling-book adopted is given on p. 108.

In this survey, the distances were measured in metres. The hanging-compass used was divided into half-degrees, which were subdivided by the eye into tenths of degrees. The clinometer was also read to tenths of degrees. The figures obtained by calculation, in the "base" and "perpendicular" columns, are usually entered in red ink. If the survey is to be plotted trigonometrically or by means of the protractor, the observed bearings are first corrected for the magnetic declination. The table on next page is an example of the method of booking recommended at the Freiberg School of Mines.

In the Harz, where a thin wire is used instead of a cord, the station-line is, if possible, made 10 metres in length. The trigonometrical calculations are thus greatly facilitated, especially if logarithms are used. The form of dialling-book adopted when the compass is divided into hours, is shown on p. 109.

CARL MINE, ALSACE.—SURVEY OF ADIT LEVEL WITH THE HANGING-COMPASS.

Begun at × on right Timber, at entrance to Level.

No.	Length.	Inclination.	Bearing.		Base.	Perpendicular.		Remarks.
			Observed.	Corrected.		Rise.	Fall.	
..	1·34	R. 90°·0	..	..	..	1·34	..	To ×
A	7·36	0°·0	240°·9	228°·9	7·36	..	..	..
B	5·41	R. 3°·1	210°·3	198°·3	5·40	0·29	..	..
C	6·83	F. 1°·2	210°·2	198°·2	6·82	..	0·14	..
D	4·81	R. 3°·8	186°·6	174°·6	4·80	0·31	..	..
E	6·24	F. 0°·4	202°·8	190°·8	6·24	..	0·04	..
F	4·68	R. 1°·1	173°·1	161°·1	4·68	0·09	..	..
..	1·32	F. 90°·0	..	..	..	..	1·32	To floor of level.

The right-hand page of the survey-book is reserved for sketches, showing the position of the offsets taken.

Plotting the Survey.—The survey may be plotted by means of the compass that was used underground. The plotting instrument (Fig. 35) consists of a truly rectangular plate of brass, 10 inches long and 5 inches wide, with a raised ring in the middle for the reception of the compass-box. The diameter of the ring parallel to the long side of the plate is marked on its surface by means of two fine lines. The compass-box is placed in the ring, and clamped so that the 12-hour line coincides with these two lines. The upper edges of the rectangular plate are bevelled, so as to diminish the shadow on the paper.

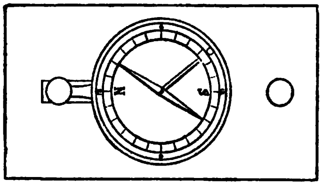

Fig. 35.

The paper on which the plan is to be drawn, is fastened to a horizontal table. The plotting-instrument is then placed on the paper, and turned until the marked end of the needle points to

DOROTHEA MINE, CLAUSTHAL.—SURVEY OF PART OF THE 19TH FATHOM LEVEL WITH THE HANGING-COMPASS.—Magnetic Declination, 13° 45′ W.

No.		Compass.				Base.	Inclination of Cord. Rise or Fall.	Length of Inclined Cord.	Perpendicular.		Remarks.
From	To	E. or W.	Hour.	⅛	1/16				Rise.	Fall.	
						Metres.		Metres.	Metres.	Metres.	
×	A	E	9	5	9	6·358	F. 12°00′	6·50	..	1·351	..
A	B	E	9	1	15	11·917	R. 6°42½′	12·00	1·402	..	..
B	C	E	7	0	0	7·430	F. 7°50′	7·50	..	1·022	..
C	D	E	9	0	12	9·868	R. 9°20′	10·00	1·622	..	..
D	E	E	9	1	0	10·913	F. 7°12½′	11·00	..	1·380	..
E	F	E	10	2	0	9·919	R. 7°17½′	10·00	1·269	..	..
F	G	E	9	7	9	9·911	F. 7°40′	10·00	..	1·334	..
G	H	E	10	0	1	9·868	R. 9°20′	10·00	1·622	..	..
H	J	E	10	4	8	9·872	F. 9°10′	10·00	..	1·593	..
J	K	E	10	5	4	9·907	R. 9°50′	10·00	1·363	..	..
K	L	E	9	7	8	10·481	F. 7°00′	10·56	..	1·287	..
L	M	..	..	..	..	..	R. 90°00′	1·34	1·340	..	..

the north. A line is then drawn along the side of the plate which will represent the north line of the plan. A point for commencing the plotting is selected, and the instrument turned at that point until the needle points to the bearing of the first line. A line is then drawn along the side of the instrument, and the required distance measured with a scale.

This method presents the advantage of plotting the survey with the actual instrument used to make it, and consequently with the same degree of approximation. But the errors due to magnetic influences are not eliminated, as the conditions are not the same as they were in the mine. In a drawing office, too, there are always iron objects that may affect the needle. At the French collieries of Decize in Nièvre, a drawing office has been built in which all the ironwork has been replaced by copper for the purpose of employing this instrument without inconvenience.

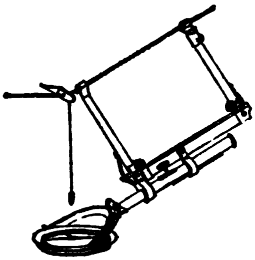

Fig. 36.

Surveying with the Hanging-compass in the Presence of Iron.—Numerous attempts have been made to modify the construction of the hanging-compass in such a way that it can be used for surveying over iron. Perhaps the most successful is the adjustable hanging-compass (Fig. 36), invented by Mr. Penkert* of Beuthen. It is so arranged that it can be centred under the point of junction of two cords and thus the bearing of the two lines can be taken from the same place. The instrument is manufactured by A. Ott, of Kempten, Bavaria.

In all instruments constructed on this principle, there is the disadvantage, apart from the difficulty of centring the magnetic-needle with a small plumb-line, that when cords with different inclinations come together, the position of the point of suspension of the needle differs vertically on the two cords, and, consequently, the essential feature of the method is defective. This drawback has been obviated by a hanging-compass invented by Mr. Oscar Langer, of Clausthal, in which the point of suspension of the compass, which remains unmoved, forms the apex of the angle to be measured.

Use of the German Dial.—The hanging-compass in Germany and France is being replaced by the theodolite; but it is still found useful in narrow workings. It is occasionally used in America. Thus, in surveying the Longdale iron mine in Virginia, Mr. G. R. Johnson has found it a useful auxiliary.* The four main adit levels of the mine having been surveyed, and their entrances connected by level and theodolite lines, it remained to survey the stopes and workings in order to make a complete map, and to test the accuracy of the foregoing work. To do this with the theodolite and level was out of the question, both on account of the roughness of the workings, and also because they were much too small—so small in places that a man could scarcely crawl through them. The hanging-compass was consequently used with very satisfactory results, the ends of the survey coinciding with the corresponding points determined in the theodolite survey. A modification of the stretched string method has been used with success by Mr. F. L. Burr † in surveying secondary mine openings in the Lake Superior iron ore mines, the hanging-compass being dispensed with and the angles between the strings measured.

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* *Berg. H. Ztg.*, vol. xxxix., 1880, p. 9.

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* *Trans. Amer. Inst. Min. Eng.*, vol. xx., p. 104; vol. xxix., p. 993.

† *Engineering and Mining Journal*, vol. lxxx., 1905, p. 566.

CHAPTER IX.

THE VERNIER DIAL.

Principles.—The instrument, in so far as its application to traversing independently of the magnetic-needle is concerned, consists essentially of a graduated circle, which can be set and rotated in a horizontal plane, and provided with sighting vanes, forming a line of sight, which can be rotated concentrically with the graduated circle. A vernier moving with the sighting vanes enables the angle turned through by the line of sight to be measured on the graduated circle.

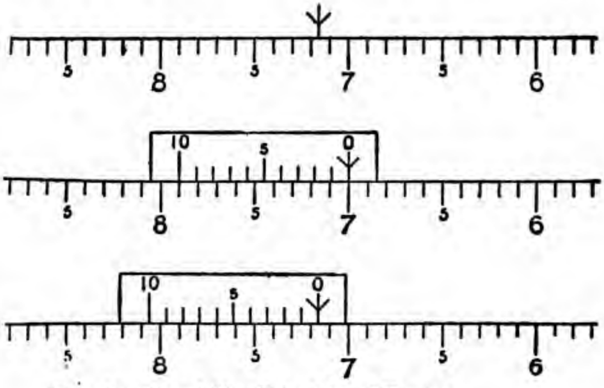
The Vernier.—The vernier, which was invented in 1631 by Pierre Vernier, consists of a short graduated slide arranged to move in contact with the scale in conjunction with which it is used. Verniers are graduated so that each of the divisions is slightly smaller or larger by a definite amount than the smallest divisions on the main scale, thus giving rise to two types of verniers, those in which the vernier divisions are smaller than the scale divisions read in the same direction as the scale, and are hence known as direct or forward verniers, and those in which the vernier divisions are larger than the scale divisions read in the reverse direction to that of the scale, and are known as retrograde verniers.

In surveying instruments, and in most instruments in which it is employed, the vernier serves a double purpose, acting as an index and also as a subdivider for the scale. The principle and use of the vernier can be best explained by reference to a vernier employed to read a scale to one-tenth of the smallest divisions. Fig. 37 represents a scale of inches and tenths of an inch, and it is desired to take the reading of the scale at the point indicated by the arrow correct to a hundredth of an inch. In order to do this a vernier is employed, which is divided so that ten divisions on the vernier are equal to nine on the scale. If we now move the vernier along until it occupies the position shown in Fig. 39, so that the vernier corresponds to that of the arrow in Fig. 37, the correct reading of the scale within the limits set out is obtained as follows :—The reading up to the last division before the zero of the vernier is observed ; in this case it is 7·1. The number of divisions on the vernier up to the point where a division line on the vernier coincides with one on the scale is counted. In the example given the coincidence occurs at the sixth division, and this gives the number of hundredths of an inch to be added to the first reading ; the full reading in the example is thus 7·16. That the interval between 7·1 and the zero of the vernier is equal to ·06, will be apparent from the following reasoning :—First, the number of divisions on the vernier between its zero and the point of coincidence is equal to the number of divisions on the scale between the point of coincidence and the division immediately

Fig. 37.

Fig. 38.

Fig. 39.



Figs. 37, 38, and 39.—Principles of Vernier.

before the zero of the vernier. Then the value of each of the smallest scale divisions being 0·1″, that of each of the vernier divisions $= \frac{0 \cdot 1 \times 9}{10} = \cdot 09''$. The value of the interval then equals $(6 \times 0 \cdot 1) - (6 \times 0 \cdot 09) = 0 \cdot 06''$. Taking now the general case for direct verniers, where n equals the number of divisions on the vernier corresponding to $n - 1$ divisions on the scale, the value of each vernier division equals $\frac{n-1}{n}$ times that of the smallest scale division. If x represents the number of divisions up to the point of coincidence, the value of the interval between the zero of the vernier and the division on the scale immediately preceding equals $x - x\left(\frac{n-1}{n}\right) = \frac{x}{n}$ in terms of the smallest scale divisions.

The same reasoning applies to retrograde verniers, where n divisions on the vernier are made equal to $n + 1$ divisions on the scale, but in this case the coincidence occurs behind the point on the scale where the reading has to be taken, so that the vernier reads backwards. Retrograde verniers are very rarely employed on surveying instruments, but one example of their use which should be noted is in the case of the mercurial barometer, where verniers of this type are not infrequently used for reading off the height of the column of mercury at any particular time.

The verniers employed in surveying instruments vary according to the graduation of the circles with which they are used and the degree of accuracy to which they are required to read, this being determined by the difference in the value of the divisions on the vernier and of those on the circle. This difference is known as the least reading or least count of the vernier.

The least reading of any vernier can be found from the following formula :—Least reading $= a\frac{n-(n-1)}{n}$, in which a represents the value of the smallest division on the circle, and n represents the number of divisions on the vernier corresponding to $n - 1$ divisions on the circle.

The least reading of the verniers employed in dials is usually three minutes though verniers reading to single minutes are not uncommon. The verniers in theodolites used for mining work are usually arranged to read to single minutes or thirty seconds. An example of a vernier to read to three minutes is shown in Fig. 40. In this case the circle is divided into degrees, and twenty divisions on the vernier are equal to nineteen on the circle. The vernier of a theodolite arranged to read to single minutes is shown in Fig. 41. The circle is divided into half-degrees, and 30 divisions on the vernier are equal to 29 on the circle. It is a common practice at the present time to make the centre division of the vernier the zero, as shown in Fig. 42, so that in some positions the coincidence occurs behind the zero. Such verniers are rather confusing at first, and the advantages of this method of dividing are, to say the best, obscure. They are not to be confused with retrograde verniers, as they are read forwards from the zero, and again from the 30 minute divisions on the right, which, as will be seen, occupies an exactly corresponding position with reference to the nearest circle division as the one on the left does to the circle division nearest it.

Double verniers are sometimes provided in theodolites, more especially in American instruments. In such verniers the zero is placed in the centre, and a coincidence occurs on either side of this, but only one or other side of the vernier is read according to the direction in which it is desired to read the circle.

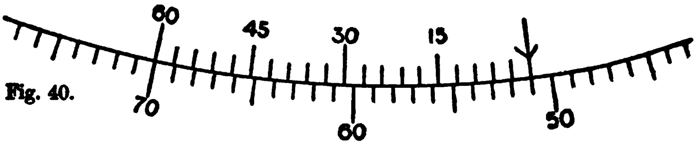


Fig. 40.

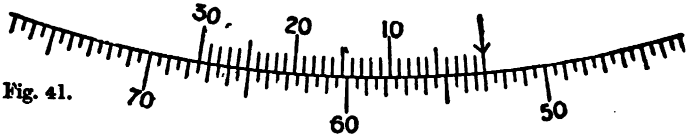


Fig. 41.

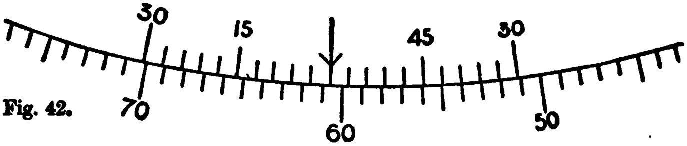


Fig. 42.

Figs. 40, 41, and 42.—Examples of vernier.

Various Forms of Vernier Dials.—These may be classed under two heads—viz., inside vernier dials and outside vernier dials. In both these types of instrument a magnetic-needle is provided so that they can be used for loose-needle traversing as well as for fixed needle work. They differ from one another essentially in that in the inside vernier type the horizontal graduated circle used for measuring angles off the magnetic meridian is also used for measuring angles with the vernier. Whilst in the outside vernier dials two horizontal graduated circles are provided, one for use solely with the magnetic-needle, the other solely with the vernier.

As already explained in Chapter VI, the graduation of the compass ring in the miner's dial is contra-clockwise, so that normal magnetic azimuths are read off directly with the needle. This practice is also usually followed in the case of inside vernier dials, and as the same graduations are used for the needle and vernier, the angles obtained with the latter are reversed, or are, as it is sometimes termed, left-handed. In order to obtain normal directions from the observations taken with such a dial, each of the vernier readings must be subtracted from 360°.

Since in the outside vernier dial separate graduated circles for use with the needle and vernier respectively are provided, the contra-clockwise graduations on the compass-ring can be retained, whilst the circle for use with the vernier can be graduated clockwise, so that normal angles are read off both with the vernier and the needle. In many outside vernier dials, however, the compass-ring graduation is clockwise and the vernier circle graduations contra-clockwise, so that both loose-needle and vernier readings are reverse from the normal. There seems to be no adequate reason why such a practice should ever have been introduced, as it leads to confusion in comparing surveys made with the miner's dial on the one hand and the theodolite on the other. Most makers, however, will provide instruments graduated to comply with a given specification, and it is strongly advised that a surveyor, in ordering an outside vernier dial, should stipulate that the graduations should be contra-clockwise on the compass-ring and clockwise on the vernier circle.

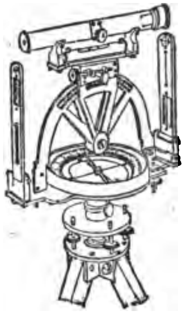


Fig. 43.

Inside Vernier Dials.—Various forms of this type have been introduced, which only vary in minor details. Lean's dial is of this type, and was for many years very popular. An outside view of this form of dial as manufactured by W. F. Stanley & Co., Ltd., is shown in Fig. 43, whilst Fig. 44 represents the internal arrangement. As will be seen from the latter figure, the compass-box is composite, and the dial may be considered to consist of two parts which move relatively with regard to one another, the compass-ring *a* and the socket-piece *b*, rigidly connected by means of screws, forming one part, and the outer portion of the compass-box, to which is attached the vernier *c*, and the plate *d*, which carries the sight-vanes (not shown in figure), forming the other part. These two parts can be locked together by means of a pin *f*, which can only be inserted when the zero of the vernier coincides with the zero of the graduations on the compass-ring.

The dial is attached to the spindle of the ball-and-socket joint by means of the socket-piece *b*, and when the screw *h* is loose rotation of the socket-piece can be effected. When the pin *f* is in position, the dial can thus be rotated as a whole; with the pin removed, rotation of the outer portion of the compass-box with the parts attached can be effected independently of the compass-ring, which can be left clamped, by turning the milled head *e*, which causes the pinion *g* to move round the compass-ring, the lower outside edge of which having teeth cut in it forms a large pinion. The effect of this movement is to cause the plate *d* and all its attachments to rotate.

The instrument is provided with spirit levels and a graduated arc for measuring vertical angles, and a telescope so that the instrument may be used as a theodolite for surface-surveys. The vertical arc and the telescope may be removed, and the sights used. The latter are made to fold down for convenience in packing. Underneath the compass-box is a sliding piece to throw the needle off its pivot so as to preserve it when not in use.

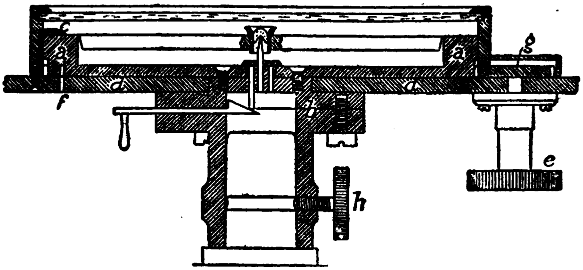


Fig. 44.—Inside vernier dial.

The Henderson Dial is a modified form of the Lean dial, and is represented in Fig. 45.

In the construction of the sights, the use of horse hairs is avoided, as they are liable to get burnt by a flaring candle underground. In place of the ordinary horse-hair sights, the *split-sight* is adopted. There is a narrow slit in each sight, through which the object can be distinctly seen, and its bearing determined with precision. On the other hand, if the vertical hair is used, it covers to a certain extent the object, which should be seen sharply defined.

The needle is mounted on a ruby instead of the ordinary agate. Consequently, care must be taken to throw off the needle when not required, as the shock caused by placing the tripod suddenly on the ground is apt to crack the ruby, which though extremely hard, is brittle.

To the north-seeking end of the needle, an aluminium vernier is fixed, the needle being counterbalanced at its other end. By the aid of this contrivance, a bearing can be read to three minutes, a degree of precision sufficient for general purposes.

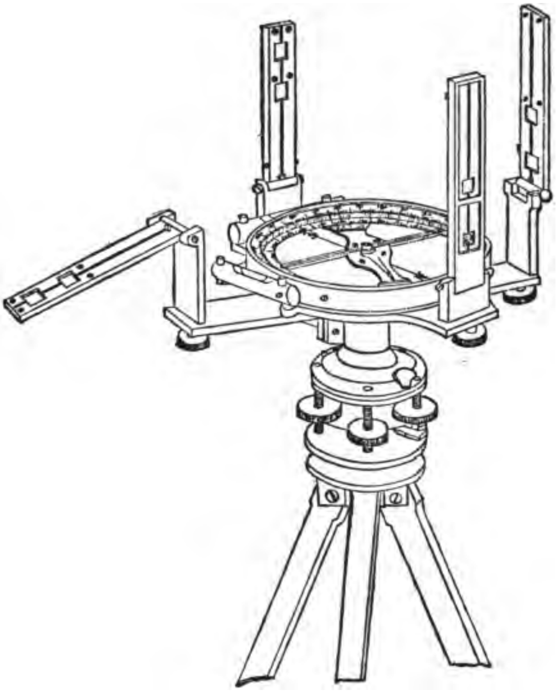


Fig. 45.—Henderson dial.

The special feature of the dial is the attachment to the instrument of two sets of folding sights, one revolving within the other. The fixed sights are always in a line with the back object in fast-needle surveying; whilst the inner or revolving sights adjusted to the forward object give the angle of deviation from the original direction. The sights are made to fold over so as to be out of the way, in case the new line should too closely approach the direction of the old one. From the joints of a dial working loose, an imperceptible movement will sometimes take place in the body of the instrument on turning it in a new direction. There results, of course, an error in the angle obtained when looking towards the forward object. In the Henderson dial, however, the back object can be again sighted through the fixed sights, and re-adjusted should any deviation be observed.

For taking vertical angles, a semicircular vertical arc is fixed across the central line of the dial, when required. It is provided with a movable limb, to which a vernier is attached, as well as a horizontal bar carrying a pair of sights and a long spirit-level. A folding shutter is fitted to each sight, with the object of precluding the possibility of the eye being directed to the wrong orifice.

This dial, which has not been adopted to any extent, was invented by Mr. J. Henderson M.Inst.C.E.,* and is manufactured by Mr. Letcher, of Truro.

Outside Vernier Dials.—These dials are rapidly replacing the inside vernier type, and most makers of surveying instruments are now supplying this form. The instrument, as manufactured by John Davis & Sons, of Derby, is shown in Fig. 46, which represents a general view. The design has been well thought out, and the dial is very satisfactory for all-round use.

As will be seen from the figure, it is a modification of the Hedley dial, the sights being attached to a swinging frame to enable the instrument to be used in highly inclined workings. The internal construction is shown diagrammatically in Fig. 47, which represents a section through the centre. The horizontal circle *a*, graduated on its bevelled edge, is bossed in the centre, which is hollowed to receive the vertical axis *b*, which is rigidly attached to the lower side of the compass-box. At the bottom of the latter is a plate which is constructed to overlap the horizontal circle *a*, thus protecting the graduations; this plate carries the vernier *c*. The graduated circle and vertical axis are held in position by means of the disc *d*, which is so attached as to permit relative motion between the parts it holds together. The method of attaching the dial to the tripod varies with the form of dial joint adopted, but the attachment is always performed through a socket-piece rigidly attached to the graduated circle by means of screws. A clamp, which is not shown in the section, enables the compass-box with its attachments, which include the vernier and the sighting-vanes, to be locked together when desired, so that, as in the case of the inside vernier dial, the instrument can be rotated as a whole when the screw *e* is loose, whilst on tightening the latter and loosening the clamp the sight-vanes and vernier can be rotated independently.

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* *Proc. Min. Inst., Cornwall*, vol. i., 1883, p. 317.

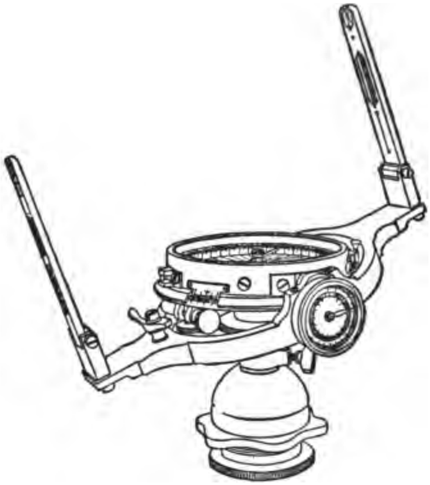

Fig. 46.—Outside vernier dial.

Two spirit-levels at right angles to one another are set in the bottom of the compass-box for the purpose of levelling the instrument.

The Hedley form of side arc for taking vertical angles is replaced by a fixed circular box 1$\frac{3}{4}$ inches in diameter, with a hand traversing a dial-plate divided into 90°. This form of

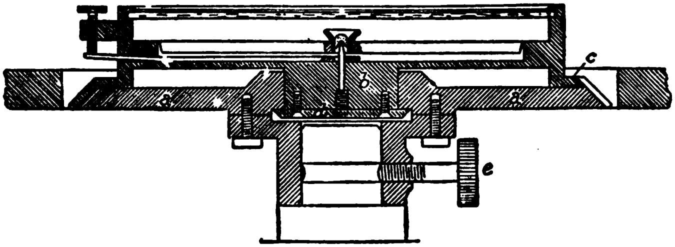

Fig. 47.—Outside vernier dial.

arc presents the advantages of always being in position, and of being so compact that it does not interfere with the manipulation of the screws under the body of the dial.

For surface-surveys, a telescope may be substituted for the sights. The tripod on which the dial is supported is made of mahogany, with a brass screw-joint at the centre of each leg. For very shallow workings, it is necessary to have an extra set of joints in the legs. All the joints in the legs are made interchangeable, and great rigidity is obtained by increasing the diameter of the legs towards the centre.

Whitelaw's Dial.—In this instrument (Patent 1878, No. 1592) the compass and lower limbs are of the same diameter (Fig. 48). The vernier is attached to the outside of the compass-box, and is placed close to the right of the line of sight, so that readings can be taken by the surveyor directly after sighting the object, without moving aside. The graduated lower plate is covered by the compass-box except at the vernier. A circular spirit-level placed inside the compass-box serves for approximately levelling the instrument before final adjustment with the long level suspended below the vertical arc.

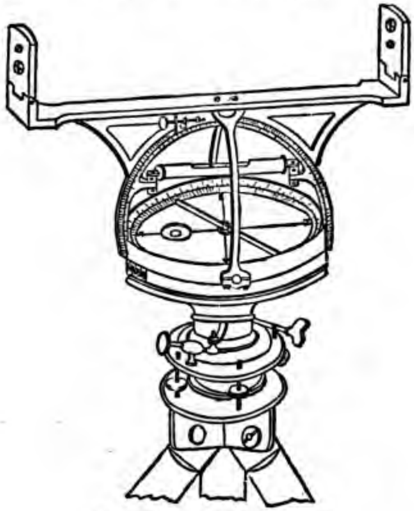

Fig. 48.—Whitelaw's dial.

The special feature of this dial is the manner in which the vertical arc is supported. In order that the compass graduation shall not be obstructed, the standards are entirely dispensed with. In their place is a movable semi-circular arc carrying the bar with the sights, or telescope if required. This arc is at right angles to the graduated vertical arc, and the axis, on which it turns, corresponds with the east and west points of the compass-box. Angles of elevation or depression up to 90° can be taken simultaneously with horizontal angles. The dial is thus well suited for surveying in metalliferous mines. It is manufactured by Mr. W. H. Harling, of London.

Thornton's Dial.—This dial is the patent of Messrs. A. G. Thornton and Co., of Manchester. Its special feature is a graduated semicircular folding arc for taking vertical angles. This vertical limb is fixed by hinge joints to the edge of the compass-box, and may be folded down out of the way of injury when the dial is being carried about in the mine. A groove is cut in the vertical limb, in which slides the bridge carrying the sights. The bridge may be fixed at any angle by a clamping screw, and to it a vernier is attached for reading vertical angles. In order to ensure the rigidity of the hinged vertical limb, a pin is provided to fix it securely, and when folded down it rests upon a ledge, and so relieves the hinged joints of strain.

The compass-plate is 6½ inches in diameter, and its edge is bevelled; the divisions are thus clearly seen, and readings can be taken very readily. The dial is provided with a vernier within the compass-box, and with two spirit-levels let into the compass-face at right angles to one another. It is attached to the tripod in the usual way by a ball-and-socket joint with clamping screw.

Grubb Sight for Dials.—Sir Howard Grubb* has invented a sight for dials, consisting of a short brass tube about 3 inches long by ¾ inch square, through which the object is viewed. About midway down this tube is fixed, at an angle of 45°, a plate of glass coated with a semi-transparent and highly reflective film. This plate reflects the light of a lamp held on one side of the tube at an opening in that side, the opening containing a piece of glass on which a cross has been marked. By this means, aided by a lens in the tube, the cross is seen, when looking through the sight, projected upon the object, and in the same vertical plane with the latter, so that the eye is not called upon to focus itself at more than one distance at the same time.

This form of sight has not been adopted to any extent owing, according to Mr. Henry Davis, to the radical nature of the change from ordinary practice, and to the difficulty of obtaining a satisfactory illumination when working underground.

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* *Trans. Inst. Mng. Eng.*, 1902, vol. xxiii., p. 118.

Tripods.—Various forms of tripod can be obtained for use with the vernier dial. For underground work, tripods such as are used with the miner's dial, but of slightly heavier construction, are quite suitable. For surface work, especially when a telescope is used in place of the ordinary sights, heavier forms of tripod, such as are used with theodolites, should be used, otherwise trouble is likely to be experienced owing to vibration set up by wind.

Dial Joints.—The connection of the dial to the tripod is usually effected through a ball-and-socket joint, such as is used for miner's dials, and except for very heavy instruments, is quite effective. Some makers supply levelling screws in addition to enable more precise levelling of the instrument to be performed than can conveniently be done with the ball-and-socket joint alone. It is very questionable whether any advantage is to be gained by their adoption, as for all purposes for which a vernier dial should be employed the levelling can be sufficiently accurately performed without them. The firm of John Davis & Sons have various forms of Hoffman joints on the market, and that which they recommend for use with their vernier dials is shown in Fig. 49.

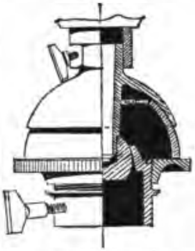

Fig. 49.

It is claimed to possess the following advantages over the ball-and-socket joint:—1. The plumb-line is suspended from the actual centre of the dial. 2. The rubbing-surface is some ten times greater, and consequently the joint is more rigid. 3. The joint is manipulated with greater ease and rapidity. A slight turn of the milled flange from right to left liberates the two concentric hemispheres. The dial is then levelled up, and a slight turn of the flange from left to right secures the joint. 4. Only one hand is required to manipulate the joint. 5. The total height of the Hoffman joint is 3 inches; that of the ball-and-socket joint 3⅝ inches. The length of the centre is 2⅛ inches; that of the ball-and-socket is barely 1½ inches. The Hoffman joint is not heavier than the ball-and-socket joint.

CHAPTER X

THE THEODOLITE.

Historical Sketch.—In mine-surveys, where extreme accuracy is required, the theodolite should be employed. There is, however, no occasion for it to be used exclusively, as the modern vernier-dial is a form of theodolite, which from its simplicity and compactness is better adapted for underground work than the theodolite itself, and proved by severe tests to give highly satisfactory results. For surface-surveying the dial is, however, decidedly inferior to the theodolite.

The employment of improved instruments for measuring angles underground in place of the compass, dates from the end of the 18th century. In 1798, H. C. W. Breithaupt, of Cassel, invented a mine-surveying instrument, resembling an *astrolabe*. This was essentially a theodolite. It had a graduated horizontal circle with verniers, a vertical arc, a sighting-tube, and a compass. Two sets of legs were used with the instrument. In the same year, Professor Guiliani, of Klagenfurt, invented a mining theodolite, calling it a *catageolabium*. Mine-surveys, too, were made between the years 1795 and 1801 by the Polish General, Komarzewski, with a *graphomètre souterrain* which he invented. Since 1832, the theodolite has been used, more or less, in all mine-surveys, where great accuracy is required. Theodolites specially constructed for mining purposes are now made in great numbers by the continental and American instrument-makers. In Great Britain, however, the tendency has been to improve the construction of the circumferenter, making it more and more like the theodolite, so that with it results can be obtained as accurate as those made with a German mining theodolite of the same size.

Description of the Theodolite.—The theodolite is the most important, but at the same time the most complicated, instrument used by the mine-surveyor. In general outline, it may be described as a telescope mounted on a horizontal and a vertical axis, in such a way that the horizontal and vertical rotation of its optical axis may be measured.

Theodolites may be divided broadly into two classes—viz., *repeating* and *non-repeating* theodolites. The latter form, which are of simpler construction than the former, are not convenient for mine-surveying, and the term theodolite will be used in this work as indicating repeating theodolites.

There are many forms of theodolite, but there are certain essential parts common to all.

These are shown in Fig. 50. The most important part is the *horizontal circle*, G, which has its edge bevelled and graduated, the degrees being numbered continuously round it towards the right up to 360°. At the centre of this circle is another circular plate, the *vernier-plate* F, capable of rotation independently of the horizontal circle. On the vernier-plate is engraved a line, the index line, passing exactly through the centre, the end-points, or indices, extending to the graduation of the horizontal circle. The indices are provided with verniers, read by means of the microscopes *g*, *g*, which are sometimes provided with plates of ivory to reflect light on the scale. The horizontal circle and the vernier-plate together are sometimes termed the *horizontal limb*, in which case G is called the *lower*

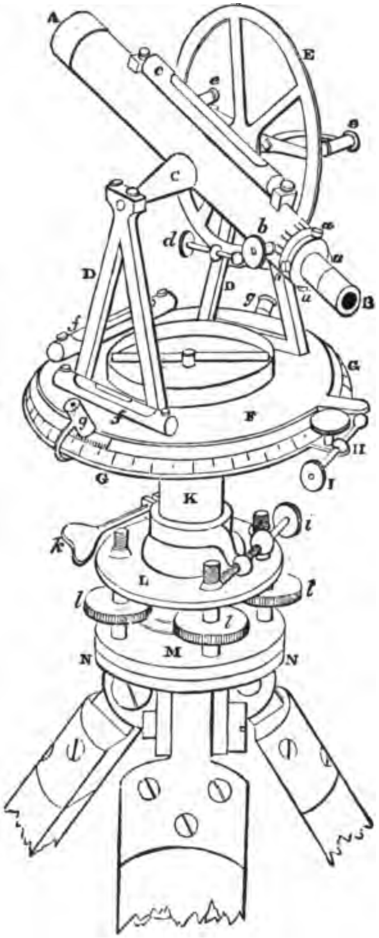

Fig. 50.

limb. The instrument-makers' names are (F) *plate,* and (G) *limb.*

On the vernier-plate are two uprights or supports, D, D, which support the horizontal axis, C, of the telescope and the *vertical* or *altitude circle,* E. The latter is provided with two indices with verniers at the opposite ends of a horizontal bar, read by the microscopes *e, e.* The telescope AB is fixed directly upon the horizontal axis.

The horizontal circle is screwed by a flange to a hollow brass vertical axis, K, known as the *body-piece,* passing through the collar of a clamp, where it may be fixed or loosened by the clamp screw, *k.* Below the collar, the body-piece works freely on a ball-and-socket joint at its lower end. The ball and socket is placed between the parallel plates, L, M, which are provided with four levelling screws, *l.* The vernier-plate, which is rigidly attached to the vertical axis proper, is provided with two spirit-levels, *f, f,* and a longer spirit-level, *c,* is attached to the telescope. The whole instrument is supported on a strong tripod stand.

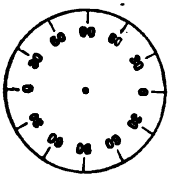

Fig. 51.

The vertical circle is usually divided into four quadrants, the degrees in each of which are numbered from 0° to 90°, as shown in Fig. 51. A continuous graduation all round the circle is, however, preferred by many surveyors. In the old-fashioned theodolite the vertical limb is a semicircle. This is surmounted by an oblong flat piece of brass, the *stage,* to the ends of which are screwed the two forked rests called Y's, by which the bell-metal collars of the telescope are supported. Under the telescope is a long spirit-level. A theodolite of this kind is termed a *plane* theodolite, whilst one with a complete circle as vertical limb is termed a *transit* theodolite. The advantages presented by the latter form are numerous, and all modern mining theodolites are of this type.

Connected with the horizontal circle and vernier-plate, there are two screws, H, I, one of which, H, is a clamping screw and the other a slow-motion or tangent screw. When H is loose, the two plates, G and F, can be moved independently, but when the screw H is tightened they can only be moved separately by means of the tangent screw I. Beneath the horizontal plates, there are two screws, *k* and *i,* one of which, *k,* is a clamping screw and the other a tangent screw. When the screw *k* is loose, the whole of the upper part of the theodolite above the screw can be rotated in either direction, in which case the horizontal circle moves upon the double conical axis upon which it rests.

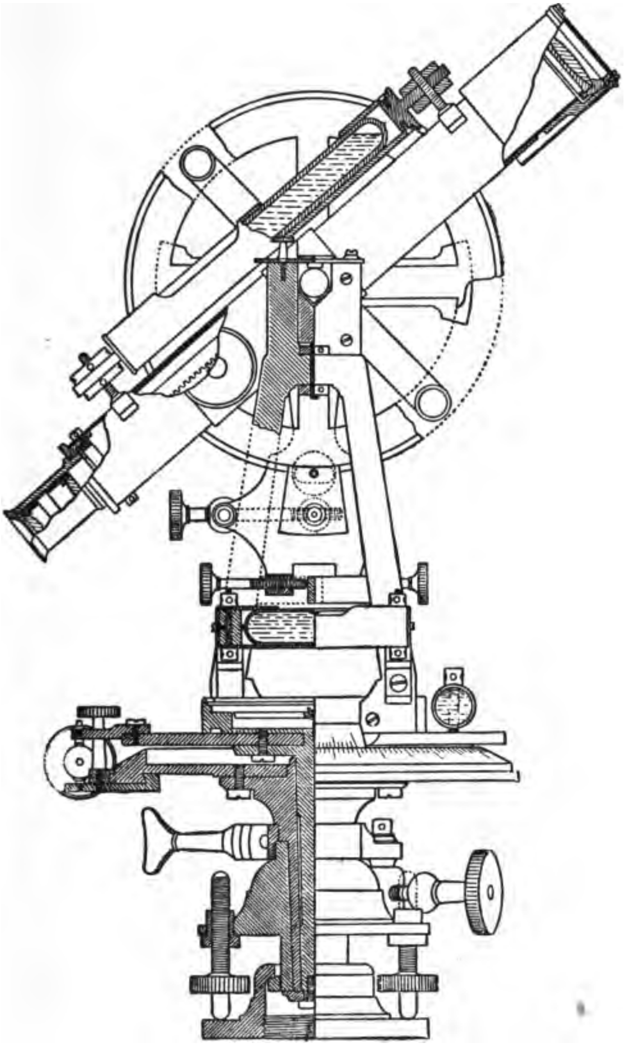

Fig. 52.

On tightening the screw *k*, the upper part can be moved only by means of the tangent screw *i*. Two screws refer to the vertical circle, a clamping screw and a tangent screw *d*. When the clamping screw is loose, the vertical circle can be moved freely; but when it is tightened, the circle can be moved only by means of the tangent screw *d*.

As an aid to memory, the screws may be divided into three sets, each of which consists of a clamping and a tangent screw. The upper set belongs solely to the vertical circle; the centre set, H, I, belongs to the horizontal circle F; and the lower set, *k*, *i*, refers to the entire portion of the instrument above it.

The circular plates with their accompanying sockets are shown in section in Fig. 52,* which shows the construction of a transit theodolite of comparatively old type, but one which is still fairly common. The upper plate carrying the compass-box, etc., is screwed fast to the flange of the interior spindle, the lower plate is fastened to the exterior socket, which in its turn is fitted to and turns in the hollow socket of the levelling head.

The telescope consists of two tubes, one sliding within the other. The object glass is achromatic—that is, made of two lenses, one of crown and one of flint-glass, the curvatures of which are suitably combined. The object glass forms between the eye-piece and its principal focus an inverted image of the object sighted, and the eye-piece, consisting of two condensing lenses, acts as a magnifying glass, and gives a virtual and highly magnified image of the inverted image thus obtained. Sometimes, especially in American instruments, the eye-piece is made up of four plano-convex lenses. An erect image is thus obtained. An erecting eye-piece, however, causes a considerable loss of light, and is, therefore, not to be recommended. It requires but little practice to get accustomed to the use of an inverting eye-piece, and the brilliancy with which objects appear, owing to the amount of light gained by dispensing with two lenses, is very marked in comparison with the results obtained with an erecting eye-piece of the same power. The telescope may be focussed by moving the inner tube by a rack and pinion turned by the milled head, *b* (Fig. 50).

The rays proceeding from the object-glass form a cone of light. In order to get a line from the point of the cone straight through the optical centre of the object-glass, and on, without deviation, to the object examined, recourse must be had to the device of *collimation*. The collimator of a theodolite telescope is a circular brass diaphragm, with a hole about half an inch in diameter in its centre, its construction being shown in Fig. 53. It is furnished with fine cross-wires, and is set in the tube of the telescope near the eye-piece, being held in position by four capstan screws known as collimating screws. The line joining the intersection of the cross-wires and the optical centre of the object-glass forms the line of sight of the telescope, and the collimating screws permit of the adjustment of this line. The adjustment of the line of sight is of the highest importance, and will be dealt with fully at a later stage.

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* Adapted from Stanley's "Surveying Instruments."

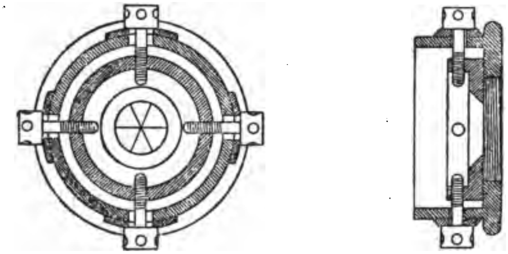

Fig. 53.

The system of cross-wires, which is sometimes spoken of as the reticule, may take the form of spider-webs or very fine platinum wires stretched across the aperture in the diaphragm. Reticules consisting of fine lines marked on thin glass discs are also employed, and are meeting with much favour, more especially since the method of producing the lines by photography has been introduced. Then again, the use of points instead of lines has long been favoured by some instrument-makers. The advantage of the latter form of reticule is that the object sighted is not obscured.

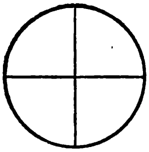

Fig. 54.

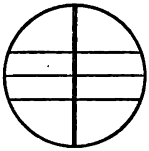

Fig. 55.

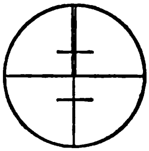

Fig. 56.

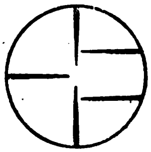

Fig. 57.

The usual form of reticule adopted in this country is shown in Fig. 53, the horizontal line being used when vertical angles are being read. A number of other forms are shown in Figs. 54 to 57. Fig. 54 shows a form of reticule largely adopted in American instruments. Figs. 55 and 56 show the forms suggested in a paper by Professor L. H. Cooke, and to which subsequent reference will be made (see p. 139). The former of these being used when the spider-web form is adopted, and the latter when the reticule is drawn on glass. In these forms the outer pairs of horizontal lines are only used when distances are being measured by means of the telescope. Fig. 57 shows a point reticule such as has been used by Messrs. W. F. Stanley & Co., Ltd., for many years. The points are made of an alloy of platinum and iridium, which is considered to be incapable of corrosion under any ordinary atmospheric conditions.

Magnetic-Needle Attachment.—The theodolite is essentially an instrument for making surveys independently of the magnetic-needle, but for the purposes of correlating surveys, especially underground, it is highly desirable that a magnetic-needle should be provided, so that the magnetic-bearing of at least one line of a survey can be measured. Until comparatively recently a compass-box, similar to that used in the miner's dial, was generally adopted, being fitted between the standards as shown in Figs. 50 and 52. Most modern instruments, however, are fitted with a trough compass, which admits of the employment of a much longer needle, the movement of the needle being restricted to a few degrees. This form of compass is temporarily attached to the theodolite as occasion requires. A full description of this and other forms of magnetic-needles will be found on p. 318.

Hoskold's Transit Theodolite.*—This instrument is a typical example of a theodolite which was designed especially for mining work, conforming to the foregoing description. A special feature is the arrangement of the upper plate, which is made to project over the lower plate at the points where the upright supports are attached, so as to enable a larger compass to be employed. Thus, a 5-inch circle will carry a 4½-inch compass; whilst in an ordinary theodolite of the same size a 2½-inch compass would be used. The Hoskold theodolite presents the further advantage that the compass is not obscured by the appendages of the upper plate. In order to enable short sights to be taken, a pair of folding sights, like those of a miner's dial, are fixed to the top of the telescope. The instrument is also provided with a diagonal eye-piece, which enables the telescope to be pointed vertically without any discomfort to the observer.

* Since this instrument was originally designed it has undergone very considerable alterations. See paper by H. D. Hoskold, *Trans. Inst. Min. Eng.*, vol. xxii.

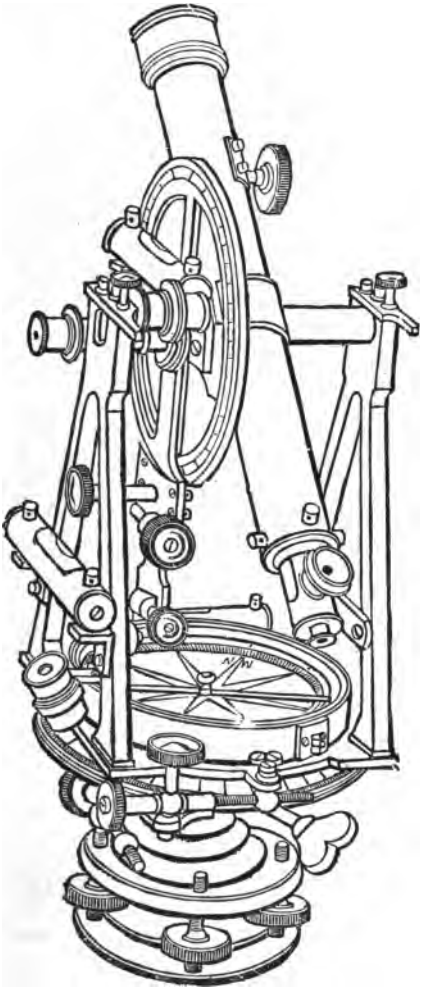

Fig. 58.—Hoskold's miner's transit theodolite.

In this theodolite and some others, a second telescope is sometimes attached below the horizontal circle. This is used like the outer pair of sights of the Henderson dial, to determine whether the circle has been disturbed during the interval between two observations.

Tribrach Theodolites.—Tribrach or three levelling-screw instruments differ very considerably from the four levelling-screw instruments, which have so far been dealt with. The levelling arrangements of the Everest theodolite illustrated in Fig. 59 will serve to show this. It was designed by Captain Everest, and was first made by Messrs. Troughton & Simms in 1838. The parallel plates are replaced by two stages, each carrying three diverging arms (Fig. 59) with a vertical levelling screw supporting the end of each. Each screw has a flange at its lower end, by means of which it is held down to the plate forming tne top of the staff head. The ball-and-socket joint formed between the parallel plates of the four-screw type of instrument is non-existent in the tribrach forms, and the possibility of straining the body-piece and vertical axis, due to excessive tightening of the levelling screws, is eliminated. Another advantage which under some circumstances may be of considerable importance is that the levelling of the instrument can be performed with one hand, whilst this operation with four levelling screws requires both hands.

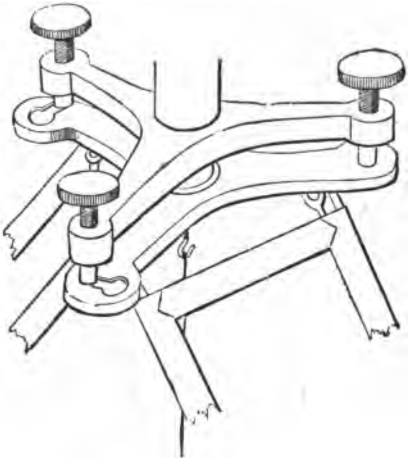

Fig. 59.

The Everest theodolite was designed for surface work, and being unsuited for general mining work, the other details of its construction will not be considered. It has been brought to notice here as illustrating an early adaption of the three levelling-screw arrangement, which is now everywhere rapidly replacing the four-screw system. A typical example of a modern mining instrument of the tribrach form, as manufactured by Messrs. E. R. Watts & Son, is shown in Fig. 60.

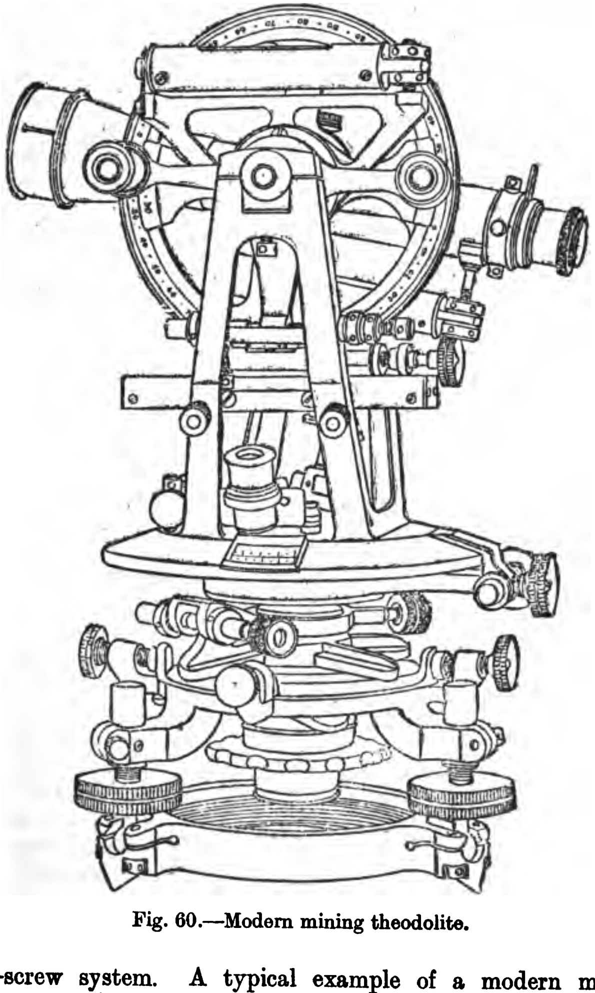

Fig. 60.—Modern mining theodolite.

Quick Levelling and Centring Heads.—In order to facilitate the setting up of the theodolite, various forms of quick-levelling tripod head have been introduced, and many of these have been incorporated with a device for accurately centring the instrument above or below a station mark without having to move the legs of the tripod, and it may here be said that some form of centring arrangement is almost a necessity for the carrying out of surveys underground with the accuracy and rapidity which present-day practice demands.

The simple ball-and-socket joint which suffices for the dial does not provide sufficient rigidity for the much heavier theodolite, but some modifications of this are quite effective.

Hoffman Tripod Head.—In its original form this was simply a device for quick-levelling, but, as modified by Professor J. H. Harden, of the University of Pennsylvania, and as shown in Fig. 61, a centring device has also been incorporated. On unscrewing the levelling screws, the plate forming part of the socket of the small ball, the centre of which is the axis of the instrument and the point from which the plummet is suspended, can be moved in any direction within the limits of the inside opening of the screw cap. It will be observed that besides the small ball and socket, there is an extra and larger ball and socket formed by a part of the plate to which the instrument is fastened, and the part to which the levelling screws are attached. The latter part always remains parallel to the screw cap of the tripod head, on which the points of the levelling screws rest, so that whatever position the instrument may assume in relation to the tripod head, the screw will always act directly perpendicular to both plates.

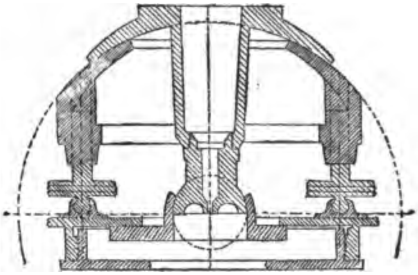

Fig. 61.

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* *Trans. Amer. Inst. Min. Eng.*, vol. vii., p. 308.

Under all conditions, the instrument moves upon a centre common to the two balls, this being the point to which the plummet is attached. It is, therefore, impossible for the plummet not to be perpendicular to the axis of the instrument.

The advantages claimed for the Hoffman tripod head are as follows :—1. A saving of one-half to two-thirds of the time usually occupied with screwing and unscrewing as in the old plan. The instrument can be levelled approximately without the use of the screws. Less than half a turn is then necessary to bring the instrument to a perfect level, the operation at the same time clamping it. 2. The levelling screws are at all times perpendicular to the plate to which they are attached, and to the plate and screw cap on which they rest. 3. The levelling screws are reduced in length, and their duty to a minimum, the instrument being no higher nor heavier than before. 4. The shifting head for plumbing over a fixed point—an improvement common to all first-class instruments—is retained, and no extra screws are required to clamp the instrument. 5. The levelling screws are covered from dust, and at the same time are no obstruction to the working of the instrument in any position in which it can be placed.

Numerous other attempts have been made to apply the ball-and-socket motion for levelling theodolites rapidly, and several American devices of this kind have proved very successful. Thus, Messrs. W. & L. E. Gurley, of Troy, have patented a quick-levelling tripod, somewhat similar in principle to that of Hoffman. The spherical surfaces are, in this case, concave, and the friction of these surfaces may be increased or diminished at will by means of spiral springs. Messrs. C. L. Berger & Sons, of Boston, furnish their theodolites with a quick-levelling attachment, which does not form part of the instrument proper, but consists of a coupling, with a ball-and-socket joint, which can be screwed between the instrument and the tripod.

In the Hoffman head as described the locking of the joint is brought about by the levelling screws themselves, and hence it is only suitable for four levelling-screw instruments. Various modifications have been introduced to render it applicable to tribrach instruments by providing means for clamping the joint independently of the levelling screws.

A very neat device for quick levelling is supplied by Messrs. Bausch & Lomb, of Rochester, N.Y. It is shown in Fig. 62, and consists of two circular wedge-shaped discs that are interposed between the levelling screws and the tripod head. By slightly loosening the levelling screws and then turning the upper disc around on the lower one, a rapid diminution of an original inclination takes place. The principle of the shifting centre can be retained in this device.

Several forms of centring device acting quite independently of the levelling arrangements are on the market; they have been mainly designed for use with tribrach instruments, and present the advantage that the final centring can be performed after levelling, thus enabling the centring to be carried out with the greatest accuracy.

One such form of centring head is that designed by Messrs. W. F. Stanley & Co., Ltd., and is shown in Fig. 63, which is taken from Stanley's *Surveying Instruments*. As will be seen, it consists of a mechanical stage, which permits of two motions at right angles. The range is from ¾ inch to 1 inch.

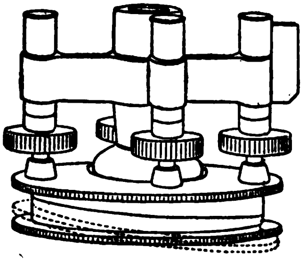

Fig. 62.

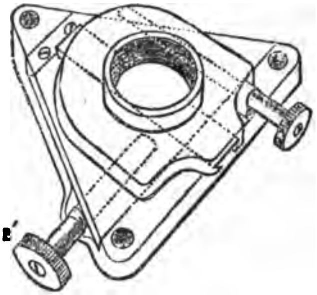

Fig. 63.

Another very convenient form supplied by Messrs. F. Robson & Co., of Newcastle-on-Tyne, is shown in Fig. 64. This, again, is a mechanical stage, which permits of lateral motion, but in one direction only. The circular portion carrying the slide is composite, and permits of a circular motion, which enables the instrument to be rotated to such a position that it can then be accurately centred by simply turning the leading screw of the mechanical stage. Two clamps are provided, one for checking the circular movement of the composite plate, and the other for locking the mechanical stage. The range of centring is about ¾ of an inch.

A centring device that admits of a much wider range of movement than any of those mentioned so far has been invented by Professor L. H. Cooke. It is fitted to the instrument shown in Fig. 60. The upper portion of the tribrach stage carries a thick metal ring, which is kept in position by two pairs of horizontally-opposed screws, and also by means of lugs cast on the boss-piece of the theodolite, which can be clamped by means of the centre clamping screw, the latter being provided with deep indentations on its edge. When this screw is loosened, coarse centring can be carried out by hand, the lugs sliding on the circular ring during this operation. The final centring can then be performed with great accuracy by means of the two pairs of opposing screws. When the centring operation has been satisfactorily performed the centre screw is tightened. The range of movement with this device is 2½ inches.

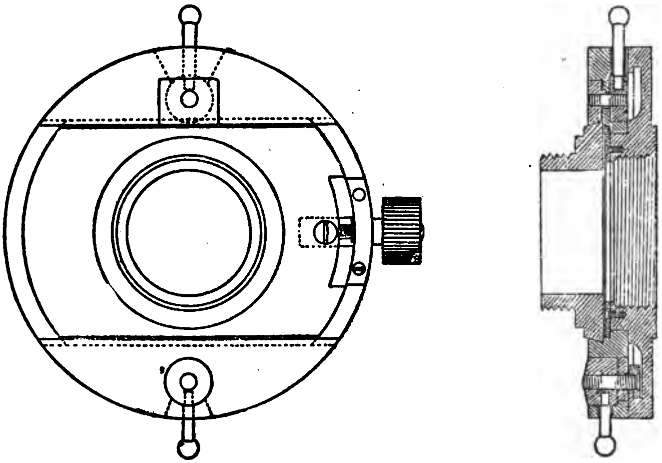

Fig. 64.

American Theodolites.—In America, the miner's dial is very rarely used for mine-surveys. In all important work, the transit-theodolite is alone used. This instrument is known in America as the *transit*. The name *theodolite* is reserved for the Y-instrument in which the telescope cannot be revolved on its horizontal axis. The transit instrument which has no vertical circle and no spirit-level attached to its telescope is called the *plain transit*.

Fig. 65 shows a theodolite of American type as manufactured by Messrs. John Davis & Son.

The limit of this work will not allow of any detailed account of the special features of theodolite design in different countries, but it should be borne in mind that instruments of great

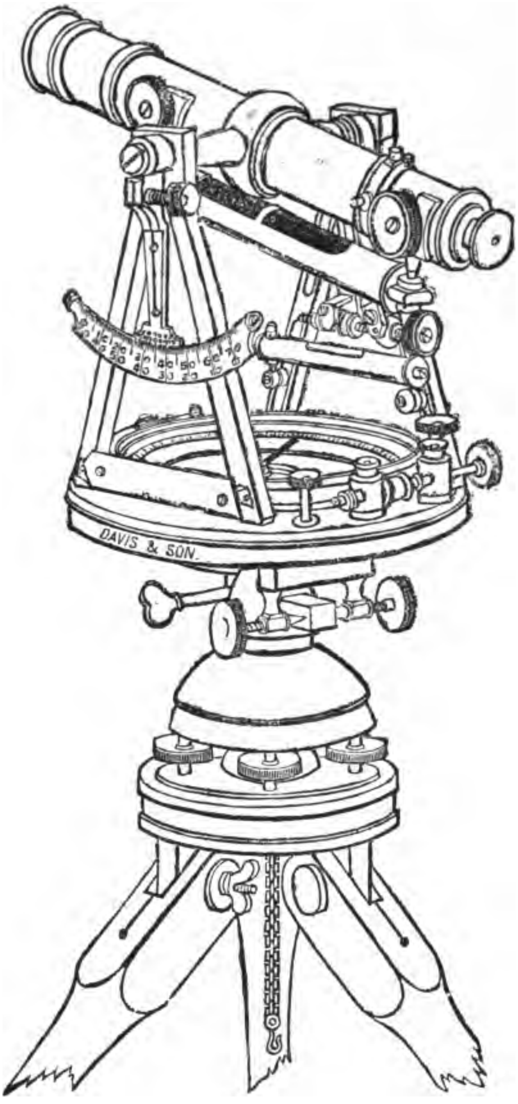

Fig. 65.—Theodolite of the American type, with Hoffman tripod head.

perfection are turned out by a number of well-known makers in America and in Continental countries.

Prospecting Theodolites.—Much attention has been recently paid to the needs of mining prospectors, and many instrument-makers can now furnish instruments provided with 3-inch circles reading to 1 minute, and which, together with tripod and case, weigh only a few pounds, and which will enable sufficiently accurate surveys for prospecting work to be carried out.

Specification of Theodolites.—In papers read before the Institution of Mining and Metallurgy by Professor Cooke of the Royal School of Mines, and in the subsequent discussions, the question of the size and design of theodolites for general mining work was very fully considered, and as practically every detail came under review, these papers and discussions are of the greatest interest and importance to all mine-surveyors.*

The instrument shown in Fig. 60 may be regarded as approximating very closely to the specification given by Professor Cooke, and to a certain extent may be regarded as the outcome of the papers and the discussions. The horizontal circle is 4½ inches diameter, reading direct to 20 seconds, 30 seconds, or 1 minute, as ordered. It is entirely protected from dust and water, and is provided with reflectors over the verniers, which very materially assist in reading the circle. The vertical circle is 4 inches in diameter, and can also, if so specified, be obtained with a protecting cover. The telescope, which is provided with an internal focussing arrangement, can be focussed for distances ranging from a very few feet up to infinity, and is so constructed as to be impervious to moisture. The magnetic compass is of the trough pattern, and when in use is attached to the standards. The centring arrangement, which has been already described, is perhaps the most remarkable feature of the instrument.

In drawing attention to this particular instrument as embodying most of the features of modern theodolite design, it is necessary to state that the design of theodolites for mining work has in the last few years received considerable attention from a number of first-class makers in this country, and most of them supply instruments which meet as far as practicable every need of the mine-surveyor.

Tripods.—The tripod for supporting the theodolite must be of very rigid construction. The commonest form used in this country is of the solid type, the section of each leg being such that when the three legs come together they form a more or less cylindrical-shaped staff very convenient for carrying about. Framed tripods of a telescopic pattern are now superseding the solid types, and for underground work in metal mines and for surface work in rough, mountainous country are very much to be preferred. The legs of the telescopic tripods consist usually of a substantial shank of circular section, sliding between two suitably-shaped pieces, which are held together by metal bands and provided with clamping screws for retaining the shank in any desired position. The joint connecting each leg of the tripod to the head-piece requires to be very carefully made, and provision must be made for keeping this sufficiently tight to eliminate all side play, as the rigidity of the whole tripod depends in a great measure on this.

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* See "Specification of a Precision-Theodolite," by L. H. Cooke, *Trans. Inst. Min. and Met.*, vol. xxii., p. 326.

For many years framed tripods have been used for theodolites larger than the 6-inch instruments. These are of non-telescopic design and very substantially built, the head-piece consisting of a heavy metal casting of triangular shape designed to admit of a very wide joint for each of the legs.

Temporary Adjustments of the Theodolite.—These are adjustments which are required every time the instrument is used, and comprise the centring and levelling-up at the station and the adjustment of the eye-piece of the telescope to eliminate parallax.

Centring and Levelling-up.—Before any angular readings are taken, the instrument must be set exactly over or under the station mark at which the observation is taken, and be truly levelled by means of the attached spirit-levels. For the purpose of centring under an overhead station mark, the centre of the instrument must be accurately marked on the telescope. This should be done by the makers, and the pop-mark usually found on the telescope of mining theodolites coincides with the vertical centre of the instrument *when the telescope is level*, and accurate centring under an overhead mark is only possible after the instrument is levelled up. For centring over stations marked on the ground a central hook, chain, or eyelet hole, from which a plummet can be suspended, is fitted to the base of the instrument. For present purposes the procedure adopted for centring *over* a station mark will be considered. A plummet weighing from 4 to 6 ounces is attached to a piece of string and suspended from the centre of the instrument. The legs of the tripod are spread out, and the instrument set as nearly as possible over the mark. The height of the plummet must be adjusted by looping the string so that the plummet is just clear of the mark. The centring is now carried out by manipulating the legs of the tripod until the point of the plummet coincides approximately with the centre of the station mark.

The accuracy with which centring should be carried out in ordinary work depends mainly on the length of the lines on either side of the station, and for general purposes it may be said that, where the shortest line involved is not less than 100 feet in length, centring to within $\frac{1}{10}$ inch is sufficiently accurate. For specially accurate work, and where very short lines are involved, the centring must be very much more precise, and the employment of one or other of the special centring devices becomes necessary. In triangulation, where, as a rule, the lines are several hundred feet long, an error of centring even up to $\frac{1}{2}$ an inch produces no appreciable error in the measurement of an angle as ordinarily carried out.*

Whilst manipulating the legs of the tripod during the centring operation, attention should also be paid to the plate levels, in order to reduce the subsequent work with the levelling screws to a minimum; and a fact well worth bearing in mind is that a considerable difference in the level of the plates can be brought about without affecting the centring to any great extent by lifting one of the legs just off the ground and turning it so that the shoe moves in a direction approximately parallel to the line formed by the other two shoes. Before the final levelling-up is carried out, it is advisable to see that the tripod is quite firm, and that there is no liability for any movement of the shoes to take place during subsequent operations.

The instrument has now to be levelled by means of the levelling screws, and the method of doing this varies somewhat according to whether the instrument is of the four-screw or tribrach type. Taking the former case first, the body-clamp of the theodolite is loosened and the limb turned until the plate spirit-levels are each parallel with opposite pairs of the levelling screws, as shown in Fig. 66. The screws are now turned in pairs—*e.g.*, 1 and 3 are turned simultaneously in the direction shown by the arrows, or if this sends the air-bubbles of the level A further from the centre, they are turned simultaneously in the reverse direction. When the bubble of this level has been brought to the centre of its run, screws 2 and 4 are dealt with until the bubble of the level B is central. The adjusting of the second level usually disturbs the first level slightly, and necessitates a fresh adjustment by means of the corresponding screws. Assuming that the plate levels are in adjustment, it should now be possible to turn the plates through a complete revolution without the bubbles being disturbed.

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* See *The Effects of Errors in Surveying*, by H. Briggs, M.Sc., published by Charles Griffin & Co., Ltd.

The tightness of the levelling screw of a four-screw instrument is a matter of considerable importance, and before starting to perform the actual levelling with the screws, it is advisable to turn each screw separately until the feet of all the screws are simultaneously in contact with the lower parallel plate. Care must be taken that each of the screws are turned an equal amount when these are being dealt with in pairs, and all the time a slight grip should be felt. This grip must not be excessive, otherwise it generally means that a strain is being imposed on the vertical axis of the instrument.

The position of the plate levels with reference to the levelling screws whilst levelling a tribrach instrument is shown in Fig. 66*a*. In this case the screws 2 and 3 are turned in the direction shown, or both in the reverse direction, until the bubble of the spirit-level B is in the centre of its run. The screw 1 is then turned by itself until the bubble of the level A is central. It is quite feasible, although the operation cannot be performed with quite equal rapidity, to bring the bubble of the level B to the centre, by turning the screws 2 and 3 one at a time, this enables the levelling to be carried out by using only one hand.

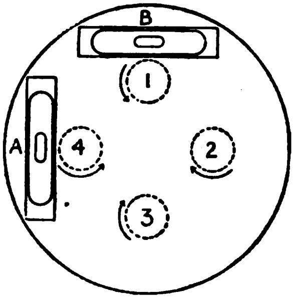


Fig. 66.

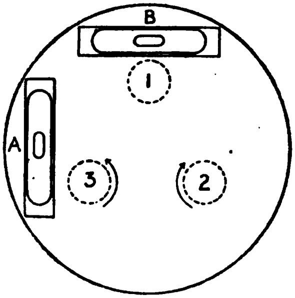


Fig. 66*a*.

In measuring horizontal angles between lines on fairly level ground, it is found that very precise levelling of the instrument is not necessary, but where the lines are steeply inclined, the levelling is of much greater importance. Vertical angles are measured generally with two objects in view, the first being to enable differences of level to be computed, and the second to enable the horizontal projections of lines to be computed. If differences of level are to be accurately determined, then the levelling of the instrument is naturally of the greatest importance, but where vertical angles are taken, as they frequently are, merely for the purpose of computing horizontal projections, then again very precise levelling is not necessary. When it is desired to level up the instrument with the greatest precision, the final levelling should be performed with the aid of the spirit-level attached to the telescope; this is usually considerably longer than the plate levels, and of considerably greater sensitiveness. The operation is conducted as follows:—After the levelling has been completed with the plate levels, the telescope is brought into an approximately horizontal position, and then the vernier attached to the vertical circle is set exactly at zero by using the clamp and tangent screw attached to the vertical circle. This should bring the bubble of the telescope level nearly to the centre of its run. The plates should now be turned so as to bring the telescope level parallel to one pair of levelling screws, and these are then turned until the bubble is exactly in the centre of its run; the plates are again turned so that the telescope now occupies a position at right angles to its previous position, and parallel to the other pair of screws, which are now used to again bring the bubble to its central position; the telescope is then brought back into its first position, and any slight adjustment necessary is made with the corresponding levelling screws. The plates are now turned through approximately 180°, thus reversing the telescope from its first position. If this operation results in the bubble taking up a fresh position, it is brought back to the centre, eliminating half the deviation by means of the levelling screws, and the other half by means of the tangent screw attached to the vertical circle. The plates are again turned through a right angle, so that the telescope now occupies a position reverse to its second position, and any deviation of the bubble is again eliminated by using the levelling screws and tangent screw. On now turning the plates through a complete revolution no movement of the bubble should take place. If it does, the adjustment must be repeated.

In most modern instruments two opposing screws attached to the clamping arrangement of the vertical circle are provided, so that the levelling adjustment can be performed without using the tangent screw which controls the movement of the vertical circle with reference to its vernier; thus, after the vernier has been set to zero, it remains in that position until the levelling has been satisfactorily performed. The movements that are otherwise performed with the tangent screws are made with the two opposing screws. On instruments not provided with the opposing screws, it may be found that when the levelling has been performed with the telescope level, the zero of the vernier does not coincide exactly with that of the graduations of the vertical circle, and the discrepancy, which is known as the *index error*, must be noted, and the vertical angles taken must be corrected accordingly.

Parallax.—When the image of the object viewed, formed by the object glass, either falls short of or beyond the place of the cross-wires, an error arises, which is called *parallax*. Its existence may be detected by moving the head from side to side when looking through the telescope, observing whether the image appears to move. To correct this error, the eye-piece must first be adjusted by means of the movable eye-piece tube, until the cross-wires are seen clearly defined. Then direct the telescope to some distant object, and by means of the milled-head screw *b* (Fig. 50), at the side of the telescope, move the inner tube in or out until the proper focus is obtained. When disregarded, parallax may give rise to serious error.

Permanent Adjustments.—In addition to the temporary adjustments described above, there are certain permanent adjustments which should be tested from time to time, but which in a well-made theodolite subject to careful treatment seldom require correction. In testing adjustments, extra care must be taken in levelling up the instrument, which should for this purpose be set up on very firm ground. Careful attention should be paid to the tripod to see that it is quite rigid, and in this connection it may be remarked that want of rigidity is very often due to the joints connecting the legs to the head having worked loose; means are generally provided for tightening up these joints. When the legs have been extended and the shoes firmly bedded in the ground, before attaching the instrument itself the tripod head should be firmly grasped with both hands and an attempt made to twist it round. This should be impossible, even to a slight extent, and if any movement is felt the joints must be tightened up. The screws connecting the joints to the timber of the legs themselves sometimes exhibit a tendency to come loose and cause a want of rigidity.

When adjustments requiring telescopic observations are being tested, the operations should preferably be carried out on ground shielded from the direct rays of the sun, otherwise the refraction due to the currents of hot air rising from the ground may give serious trouble.

Adjustment of Plate Spirit-Levels.—The plate levels must be parallel to the vernier-plate. This adjustment can be tested by carefully levelling up the instrument in the manner already described with the plate levels themselves. The vernier-plate is then turned through half a revolution, thus reversing the position of each of the levels end for end. If the bubbles do not remain in the centre of their runs, the levels are not in adjustment. The levelling should now be performed with the telescope level. The plate levels can then be corrected simply by turning the capstan screws provided for the purpose, until the bubbles occupy their central position. In all well-designed instruments provision is made for locking these capstan screws, and care should be taken to see that they are locked after any adjustment has been made.

Collimation Adjustments.—The line of collimation must fulfil certain conditions. The first and most important one is that it must be at right angles to the horizontal axis. Then, again, it must be parallel to the spirit-level of the telescope. Since this second condition affects observations taken with the theodolite only in so far as they relate to the determination of differences of level, and since the adjustment is carried out in precisely the same way as it is in the dumpy level, it will not be further considered here.

There are several ways of testing whether the line of collimation is at right angles to the horizontal axis, and two methods suitable for use in the field will be described. In the first method the instrument is set up on a piece of fairly level firm ground, and after the temporary adjustments necessary have been carefully made, a levelling staff laid along the ground at right angles to the line of sight and at a distance of 300 or 400 feet is sighted, and the intersection of the cross-wires of the telescope is made to bisect one of the more prominent divisions of the staff. The telescope is then lifted out of its bearings and replaced with the ends of the horizontal axis turned end for end. Great care is necessary in performing this operation not to disturb the instrument in any other respect. The telescope is now revolved vertically until the cross-wires again intersect the scale on the staff. If the reading is the same as before, the adjustment for collimation is correct. If not, the difference between the two readings represents twice the collimation error for the distance under observation. This will be apparent from Figs. 67 and 68, which represent the conditions prevailing when a very exaggerated case is considered. In Fig. 67, BC represents the position of the axis when the first observation of the staff is made at A. On reversing the axis the line of collimation is directed towards A′, as shown in Fig. 68. From the position of the perpendicular, with which the line of collimation should coincide, it is evident that the angle AOA′ is twice the angle AOP, which represents the collimation error. To correct the adjustment, turn the pair of horizontal collimating screws attached to the diaphragm, until the cross-wires intersect the scale on the staff at a point midway between the two readings obtained. To test whether the adjustment has been correctly made, reverse the axis in its bearings. The reading of the staff should remain the same.

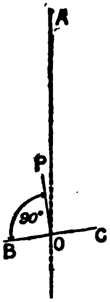


Fig. 67.

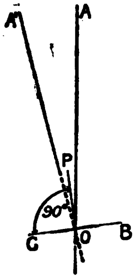


Fig. 68.

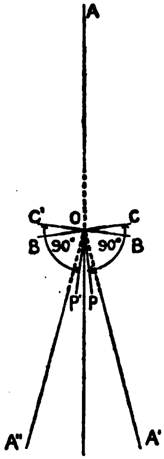


Fig. 69.

It is not always possible or at any rate convenient to reverse the horizontal axis in its bearings in the manner described above, and moreover it is not an easy matter under any circumstances to perform the operation without otherwise disturbing the instrument, and it will generally be found preferable to test and make the adjustment in the following manner :—Set up the instrument as before, and bring the cross-wires to bisect a well-defined object at about the same distance as the levelling staff used in the first method. It will be found that a steel arrow pushed twice through a piece of white paper and then into the ground forms a very satisfactory mark for this purpose. The telescope is then transited and the reading on a levelling staff laid along the ground as in the first method is observed. The distance of the staff should be about the same distance as the arrow from the instrument, only, of course, on the other side. During this operation the plate clamps are kept tight. The vernier-plate clamp is now loosened, and the plate turned through a half-revolution and again clamped, the cross-wires are now made to bisect the arrow again by the aid of the vernier-plate tangent screw. The telescope is once again transited, and the reading of the cross-wires on the levelling staff observed again. If the adjustment for collimation is correct, the first and second readings should be identical. If they are not, the difference between them represents four times the collimation error for the distance. This will be apparent from Fig. 69, in which BC represents the position of the horizontal axis on the first sighting of the object at A, which represents the position of the arrow. On transiting the telescope the first time, the line of collimation is directed towards A′, which represents the first reading of the levelling staff. When the telescope is directed towards the arrow again by turning the vernier-plate the axis occupies the position B′C′. On transiting the second time the line of collimation is directed towards A″, which represents the second reading of the staff.

The adjustment is corrected by eliminating one quarter of the difference between the staff-readings by means of the collimating screws. It can then be tested by bringing the cross-wires to bisect the mean of the extreme readings by means of the vernier tangent screw, when, on again transiting and sighting the arrow, the latter should be bisected by the cross-wires.

In the Y-theodolite, the line of collimation is adjusted by bringing the intersection of the cross-wires upon some well-defined distant object. The telescope is turned round on its collars in the Y's until the level is uppermost. Then, if the cross-wires do not continue to coincide with the object, half the difference must be corrected by moving the cross-wires, and the other half by moving the tangent screw of the horizontal circle.

Horizontal Axis Adjustment.—The horizontal axis must be at right angles to the vertical axis. In some instruments it is not possible for the surveyor to effect this adjustment, which is made once for all by the makers. This is the case with all Y theodolites, and with many of the earlier types of transit instrument. In most modern instruments of the transit type, however, provision is made for raising or lowering one of the bearings of the horizontal axis. In some cases one of the bearings consists of a block of metal sliding in grooves cut in the standard, its position being determined by a capstan screw which permits of the necessary adjustment. In other cases a vertical slot is cut in the standard from the point of the V bearing. The width of the slot is regulated by a screw let sideways into the standard. When the width of the slot is altered the V bearing opens or closes slightly, the effect being to lower or raise the end of the axis which fits into it.

The adjustment can be tested in various ways. One method is by means of a plummet having a long suspension. After the instrument has been carefully levelled up and adjusted for parallax, the cross-wires are made to bisect the plumb line at a considerable elevation, the telescope is then revolved vertically, and if the cross-wires follow the plumb-line in its mean position for a vertical angle of, say, 40°, the horizontal axis may be considered as being in adjustment. The difficulty with this method is keeping the plumb-line steady; it is practically impossible to carry out the operation out of doors, but if a lofty room with a very firm floor is available, the method becomes practicable.

A more satisfactory way of testing the adjustment is the following:—A surveyor's scale, having, say, 50 divisions to the inch, is fixed on the wooden frame of a window in a fairly high building. Vertically below this a piece of white paper with a fine vertical line drawn on it is fixed at about the height of the telescope when the theodolite is set up. The setting up is made at such a distance that an angle of about 40° is subtended by the scale and the fixed mark below it. After very carefully levelling the instrument by means of the telescope level, the line on the paper is accurately bisected with the cross-wires, the telescope is then revolved vertically, and the intersection of the cross-wires on the scale is noted. The vernier plate is then turned through half a revolution and the telescope is transited, the line on the paper is again sighted, and then after revolving the telescope the reading of the scale is observed. If the latter is the same in both cases the axis is in adjustment, if the readings do not agree the difference represents twice the error in the adjustment. To correct it, the cross-wires are made to bisect the scale at the mean of the two readings, by turning the adjusting screw of the axis. If the adjustment has been correctly performed, on revolving the telescope the cross-wires should bisect the line on the paper.

The adjustment of the horizontal axis can also be tested by a striding level. This consists of a very sensitive level mounted on two long supports, which have slots cut in them corresponding to the cylindrical portions of the horizontal axis, and enable the level to be mounted on the axis in the form of a bridge. With this instrument, if it is known to be in adjustment, the testing of the horizontal axis is a very simple matter. After carefully levelling the theodolite by means of the telescope level, the striding level is placed in position and brought parallel to a pair of the foot-levelling screws by turning the vernier-plate. As the striding level is, as a rule, more sensitive than the telescope level, it will usually be found that, even if the axis is in adjustment, the position of the bubble will require slightly adjusting with the foot screws. The vernier-plate is now turned through half a revolution, thereby reversing the position of the level and of the horizontal axis with reference to the foot-screws. If the bubble does not come to rest at the centre of the tube, the axis is out of adjustment. Correct by eliminating half the deviation of the bubble by means of the adjusting screw for the horizontal axis. To test whether the adjustment has been correctly made, eliminate the other half of the deviation of the bubble by means of the foot-screws, and on turning the vernier plate back to its former position the bubble should remain stationary.

The adjustment of the striding level itself may be tested as follows :—After placing it in position on the axis and adjusting the bubble to its centre by the foot-screws, lift the striding level off the axis and replace after reversing it end for end. If it is in adjustment the bubble will come to rest at the centre of the tube ; if the bubble deviates the level may be adjusted by eliminating half the deviation by means of the adjusting screw on the level, which is arranged to raise or lower one end of the tube. To test the adjustment, remove the other half of the deviation by means of the foot-screw and reverse the level end for end as before by lifting it from the axis ; if satisfactory, the adjustment of the horizontal axis may be proceeded with in the manner described above.

General Remarks on Adjustments.—The making of the permanent adjustments of a theodolite requires very great delicacy in the manipulation of the various parts involved, and should only be made when really necessary, as, for instance, in the event of a diaphragm being replaced. It will generally be found that the operations required for effecting them have to be repeated several times before the adjustments are satisfactory, and even when made by experienced operators it is practically impossible to make them perfect, and for precise work the methods described later for eliminating errors in the adjustments are always adopted.

CHAPTER XI.

FIXED-NEEDLE TRAVERSING.

Traversing with the Vernier Dial.—The manipulation of the vernier dial as regards setting up, levelling, and sighting is almost the same as the simple miner's dial. In fixed-needle traversing, however, each station must be occupied by the instrument, so that the question of centring comes into consideration. As a rule, there is no shifting head provided, and the centring cannot be carried out with any great precision, and care must be taken in arranging the survey to avoid short lines wherever possible, so that the effects of errors in centring are reduced to the minimum. In surface work there is usually little difficulty in avoiding short lines, but underground the case is different, and the surveyor or his assistant should always make a preliminary inspection of the course to be traversed before fixing his stations. These may be marked either on the roof or the floor, and the instrument must be set accurately over or under the station mark. If the mark is on the floor a plummet must be suspended from the centre of the instrument, and the tripod manipulated until the point of the plummet coincides with the mark. A station marked overhead with a nail from which a plummet can be suspended is the most satisfactory (see p. 171). The length of the string is adjusted so that the point of the plummet is almost touching the glass cover of the dial, and the legs of the tripod are moved until the point of the plummet coincides with the centre of the compass-needle. The instrument is then levelled up by grasping the sides of the compass-box with both hands and gently forcing it into the required horizontal position, the motion taking place about the ball-and-socket joint. This operation may result in the displacement of the centre, and if so, the tripod legs must be manipulated until the centring and levelling are sufficiently exact. A ranging rod forms the most satisfactory sighting signal for surface work, but underground the flame of a candle or lamp is used. The centring of the signal, used for sighting, is quite as important as that of the instrument, and if a lamp is used care must be taken that the flame itself is centred. A suspended safety lamp forms an ideal signal for fixed-needle traversing, as the wick is always central.

Three-Tripod System.—In this system tripods are set at each of the three stations involved in measuring an angle. The instrument is placed on the centre tripod and lamps or candles on the two outer ones. When an observation has been completed, the instrument is moved on to the tripod which previously marked the forward station, and the tripod which was at the back station is moved to form the new forward station. In this system the centring is automatic, and there is no necessity to mark the stations, although this is sometimes done as a measure of precaution. The system admits of much greater rapidity than is possible in working with a single tripod, and if the tripod heads are of suitable design, the accuracy is greater. Fig. 70 shows a tripod head of suitable form, and two brass cups of the form shown in the figure are provided for the reception of the safety lamps usually employed as signals. The cups should be of such a size that the lamp fits accurately but not tightly into the rim. The dial is connected to the tripod head in the same way as the cups—viz., through a socket in the base. The cups are provided with two spirit levels set at right angles, as shown in the figure, and it is essential in working that the spindle of the tripods be brought into the vertical position, by means of these levels, otherwise when the cup is replaced by the dial the centre of the latter may not correspond to the position of the flame of the signal flame, and serious errors thus be introduced.

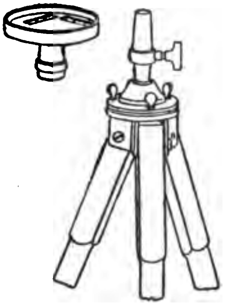


Fig. 70.

Methods Employed.—The angular observations may be made in several ways, and the angles read off with the vernier in making a given traverse vary in the different methods. The alignment of the sights can be performed equally well from either side, but, in order to avoid confusion, they must be distinguished from one another, and due care taken that the observations are made in a systematic manner. For convenience the sights may be distinguished as the north and south sights respectively, and in the case of the inside vernier dial the sight nearest the vernier may conveniently be termed the north sight, whilst in the outside vernier dial the sight nearest the zero of the graduations on the compass ring may be taken as the north sight. A sight taken with the eye at the south sight may be termed a fore-sight, and one with the eye at the north sight a back-sight. The use of the terms fore-sight and back-sight, as thus defined, is quite arbitrary, but is very convenient for explaining the difference in the methods of using the dial, and will be strictly adhered to in this connection.

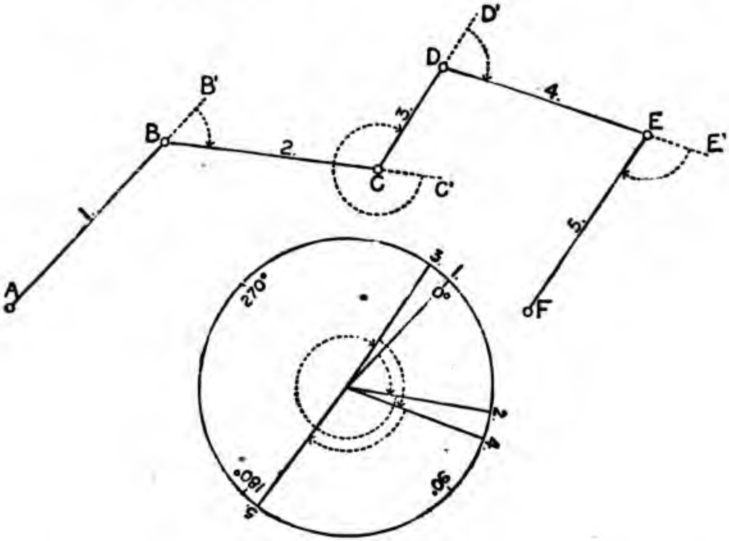


Fig. 71.

Three quite distinct methods of taking the observations may be noted, which may be described respectively as *back- and fore-sight*, *double fore-sight*, and *continuous-reading*. By whatever method the observations are made, the ultimate object is always the same—viz., to determine the direction of each line of the traverse with reference to some standard direction. The method of procedure can be best explained by considering a particular case, such as that shown in Fig. 71, in which the general direction of the traverse is ABCDEF, and the standard of direction is that of the first line, AB. The direction of each of the lines with reference to AB, as measured on the imaginary horizontal circle, is shown, and the magnitude of the angles, measured in a clockwise direction between each successive pair of lines, is indicated on the traverse and on the circle.

Back- and Fore-sight Method.—The instrument is first set up at station B. The vernier is brought to zero and clamped, either by means of the pin or the clamp provided for this purpose. The clamp controlling the motion of the dial as a whole, and which will be subsequently referred to as the body-clamp, is released and the sights turned on to the line AB, the south sight being nearest to A. With the eye at the north sight, the cross-wires are brought to bisect the signal at A. The body-clamp is tightened. The vernier-clamp is released and the sights turned in the direction of the line BC, the north sight being nearest to C. The cross-wires are brought to bisect the signal at C, the eye being at the south sight in this operation. The reading of the vernier is taken and booked. This reading is the angle B′BC measured as indicated in Fig. 71. In order to see that no movement of the graduated circle has taken place whilst taking the fore-sight, the vernier-clamp being still loose, the sights are directed back on to station A, the eye being placed at the north site for this purpose. The vernier should come to zero. If not, the whole observation must be repeated. The instrument is then set up at C, and with the vernier clamped at zero a back-sight is taken to B with the body-clamp loose, and after tightening this a fore-sight is taken to D. The vernier is read and the angle booked, and the check sight on to B taken. The vernier angle read is the angle C′CD in Fig. 71. The instrument is then removed to D, and subsequently to E, the angles at each of these stations being measured in the same way. In this method of traversing the north sight of the dial is always pointing in the direction in which the traverse is proceeding, and the vernier is always at zero whilst the back-sight is being taken. The distance for each line is measured as the survey proceeds. This should be done as soon as the surveyor has finished measuring the angle, and the distance entered in the notes before proceeding to the next setting. The notes may be entered as follows :—

Lines.	Distances.	Vernier Readings.	Assumed Azimuth.
	Links.		
1	474	..	0° 00′
2	452	55° 48′	55° 48′
3	253	294° 45′	350° 33′
4	457	75° 30′	66° 03′
5	448	106° 33′	172° 36′

The assumed azimuths recorded in the notes are obtained by calculation, as follows :—The first line being the assumed meridian, its assumed azimuth is 0°. From the position of line 2, as shown on the circle (Fig. 71), it will be evident that its assumed azimuth is equal to 0° plus the angle B′BC, which equals 55° 48′. The assumed azimuth of line 3 will be seen from the figure to be equal to that of line 2 plus the angle C′CD, which equals 55° 48′ + 294° 45′, or 350° 33′. The assumed azimuth of each of the lines can be thus found progressively by adding the vernier angle between each line and that preceding it to the assumed azimuth of the latter. It may happen that the assumed azimuths obtained during this summing process exceeds 360°, in which case this amount is subtracted from the sum. This does not affect the direction on the horizontal circle.

Double Fore-sight Method.—The method of procedure differs from that in the previous method only in that the sighting is always performed with the eye at the south sight of the dial. The dial is first set up at station B, and with the vernier clamped at zero and the body-clamp loose a *fore-sight* is taken to station A and the body-clamp tightened, the vernier-clamp is loosened and a *fore-sight* taken to C. The angle is then read with the vernier, and its magnitude is indicated in Fig. 72. The vernier-clamp being still loose, a check fore-sight is taken on to station A. The instrument is subsequently set up at each of the stations C, D, and E, the angles read by the vernier being indicated in Fig. 72. They differ in magnitude from those obtained in the previous method in that each of them is greater or less than the corresponding angle, by 180°. In this method the north sight of the dial only points in the direction in which the traverse is proceeding, when

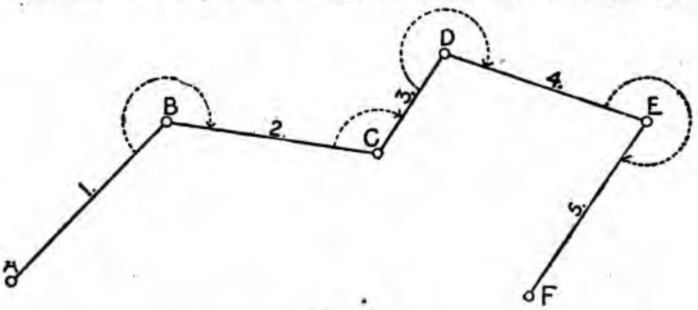


Fig. 72.

the forward station is sighted. The vernier is always at zero when the sight to the back station is being taken. The notes of the traverse are as follows:—

Lines.	Distances.	Vernier Readings.	Assumed Azimuths.
	Links.		
1	474	..	0° 00′
2	452	235° 48′	55° 48′
3	253	114° 45′	350° 33′
4	457	255° 30′	66° 03′
5	448	286° 33′	172° 36′

The assumed azimuths are obtained thus:—Line 1 being the assumed meridian as before, the meridian angle of line 2 is obtained by adding the vernier angle between lines 1 and 2 and subtracting 180°, thus—

$$(0° 00' + 235° 48') - 180° = 55° 48'.$$

The azimuths of each of the remaining lines can be found as follows:—Add the vernier angle between each line and that preceding it to the azimuth of the latter. If the sum is less than 180°, *add* 180° to it; if the sum is between 180° and 540°, *subtract* 180° from it; if the sum is greater than 540°, *subtract* 540° from it.

It should here be noted that the addition or subtraction of 180° reverses the direction of a line.

Continuous Reading Method.—In this method azimuths are read direct by the vernier. Taking the case of the same traverse as previously considered, the procedure is as follows:—The first line is again taken as the meridian for the traverse. The dial is set up at B, and with the vernier clamped at zero and the body-clamp loose, a *back-sight* is taken to A and the body-clamp tightened. The position of the sights at this juncture is indicated by the firm lines in Fig. 73, the zero of the vernier circle by the diamond and the vernier itself by the V mark. The vernier clamp is now loosened and a *fore-sight* taken to C. The position of the sights is now indicated by the dotted lines and the vernier with a V mark as before. The reading of the vernier, as will be seen from the figure and comparing it with Fig. 71, corresponds to the assumed azimuth of line 2. The vernier is clamped in this position and the dial is removed to C, and with the vernier still clamped at its last reading a back-sight is taken to B, the body-clamp being loose until the signal has been bisected; it is then tightened up. The zero of the vernier circle is now in the same relative position with regard to the assumed meridian as it was after taking the back sight at station B; and on loosening the vernier clamp and taking a fore-sight to D the vernier reading represents the assumed azimuth of line 3. The vernier is clamped at this reading and removed to station D, and subsequently to E, and the operations are repeated at each of these stations. In the diagram the position of the sights after the back-sight has been taken is shown always by the firm lines, and after the fore-sight has been taken by the dotted lines. It will be seen that at every station the zero of the vernier circle occupies the same relative position with regard to the assumed azimuth. The method is similar to the back- and fore-sight method, in that the north sight is always pointing in the direction in which the traverse is proceeding; it differs from it in that, instead of the vernier being at zero whilst the back sights are being taken, it is at the same reading as was obtained on the previous fore-sight, and the instrument mechanically performs the addition which in the back- and fore-sight method is performed by calculation.

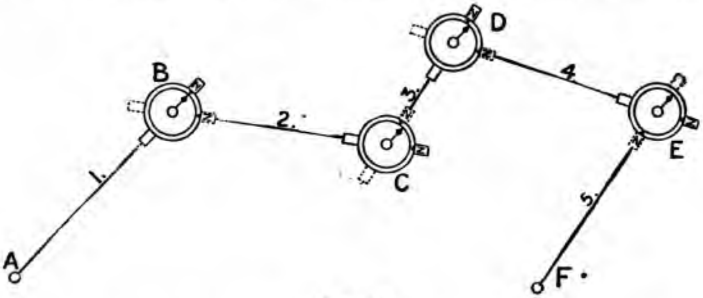


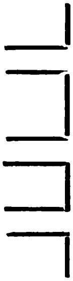
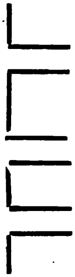
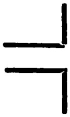
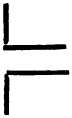
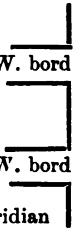
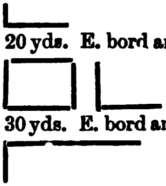
Fig. 73

Magnetic Observations with the Vernier Dial.—For many purposes it is desirable to use the magnetic meridian as the standard of direction for the traverse, and when possible the magnetic azimuth of the first line is measured. When the vernier of the dial is clamped at zero the instrument is to all intents and purposes a miner's dial, and can be used in exactly the same way for taking loose-needle bearings. The usual plan, however, when a fixed-needle traverse is being conducted on a magnetic basis is to measure the magnetic azimuth of the first line by means of the vernier. The starting point of the survey must be selected at a point free from local magnetic disturbance. After levelling up the dial, the needle is set free and the body clamp loosened; the compass-box is then turned until the zero of the compass-ring coincides with the north end of the needle when the latter has come to rest. If the dial is of the outside vernier type, it is essential that the vernier should previously have been set to zero and clamped. The body-clamp is now tightened and the vernier-clamp loosened, and a *fore-sight* taken to the second station. The reading of the vernier represents the magnetic azimuth of the line. With an outside vernier dial the reading of the needle is the same as the vernier reading; with an inside vernier dial the needle is reading zero throughout. If the subsequent fixed-needle traverse is being carried out by either of the first two methods described, the vernier is brought back to zero, and after clamping up the needle the dial is removed to the second station and the operations carried out in accordance with the previous descriptions. If the continuous-reading method is subsequently to be followed the vernier is clamped at the reading taken and retained in this position until a back-sight has been taken from the second station to the first, and as will be evident from the previous description of the continuous-reading method, this will bring the zero of the graduated circle into the same relative position with regard to the magnetic meridian as it occupied at the first station, and thus the magnetic azimuths of the remainder of the lines can be measured without the necessity of again resorting to the use of the needle.

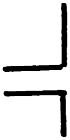
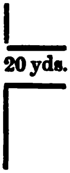
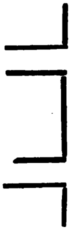
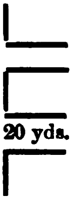
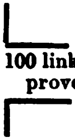
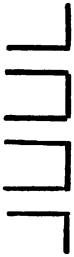
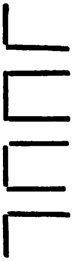
The following notes represent the survey of a portion of a Durham colliery by the double fore-sight method off the magnetic meridian.

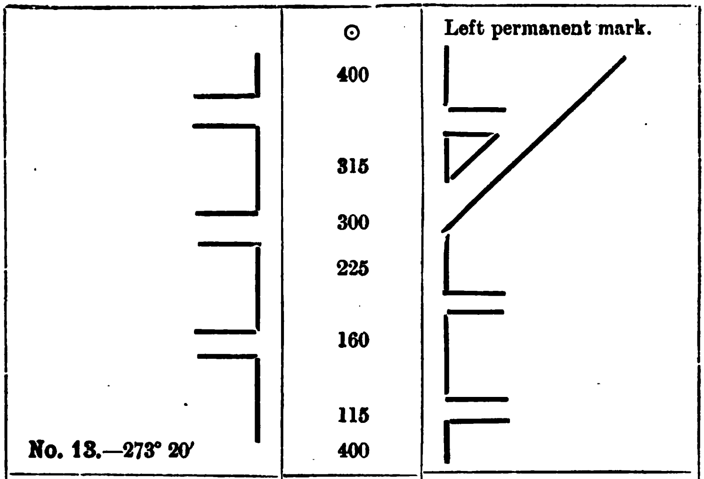
The local mining terms occurring in these survey notes have the following meanings:—A *bord* is a passage driven across the grain of the coal. A *headway* is a passage driven in the direction of the grain of the coal. A *stenton* is a passage between two winning headways. The *thill* is the floor of the mine. A *hitch* is a slight dislocation of the strata, which does not exceed the height of the seam. *Ridding* is clearing away a fall of rubbish. The *face* is the extremity of the workings.

The distances are measured in links, and, in order to avoid confusion, the total distance is first given in each draft. The first two angles were taken from the magnetic meridian. The figures $\frac{305}{1}$ denote that line No. 3 starts from the distance 305—that is, the end of line No. 1.

 **No. 4.**—131° 15′	365 250 225 100 365	 Dipper W. 3 ft.
 **No. 3.**—138° 20′ from $\frac{305}{1}$	90	 N. headways, 20 yards.
Continued 63 links to face of ridding.  W. bord W. bord **No. 2.**—343° 45′ off magnetic meridian	⊙ 299 160 100 60 299	Permanent mark left in roof.  20 yds. E. bord and holed. 30 yds. E. bord and holed.
No. 1.—340° 00′ off magnetic meridian	⊙ 305 ⊙	Permanent mark left in roof. From winding shaft.

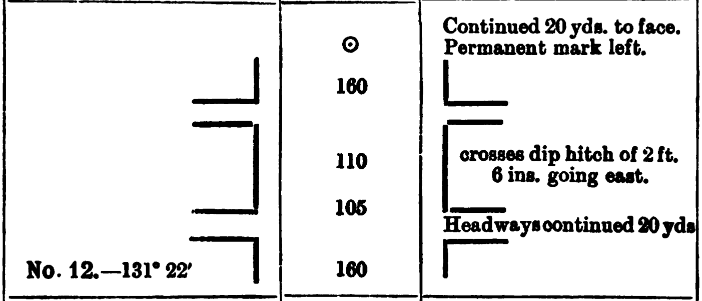
Survey from winding shaft to north face, round west and east face to pumping shaft, main coal seam.

No. 10.—94° 15′	30	Bord continued east.
 **No. 9.—93° 00′**	200 100 200	 20 yds. to rise hitch.
No. 8.—255° 32′	160	Continued 3 yds. to rise hitch.
 **No. 7.—87° 20′**	212 100 82 212	 20 yds. to hitch.
No. 6.—89° 07′	60	 100 links to hitch, rise not proved.
 **No. 5.—273° 21**	412 330 202 110 412	Continued 150 links to rise hitch, not proved. 



Left permanent mark.

No. 13.—273° 20′

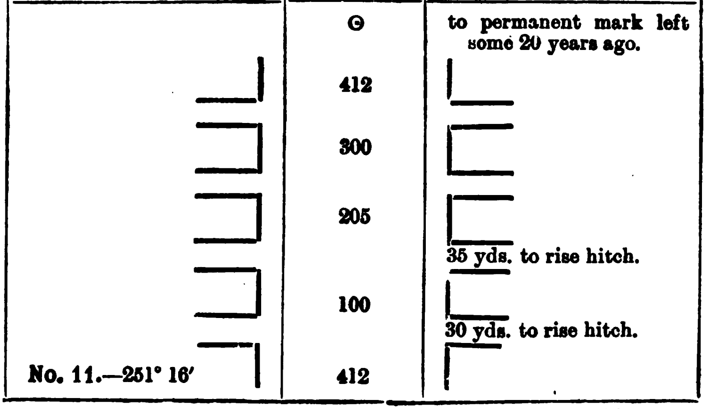


Continued 20 yds. to face.
Permanent mark left.

crosses dip hitch of 2 ft. 6 ins. going east.

Headways continued 20 yds

No. 12.—131° 22′

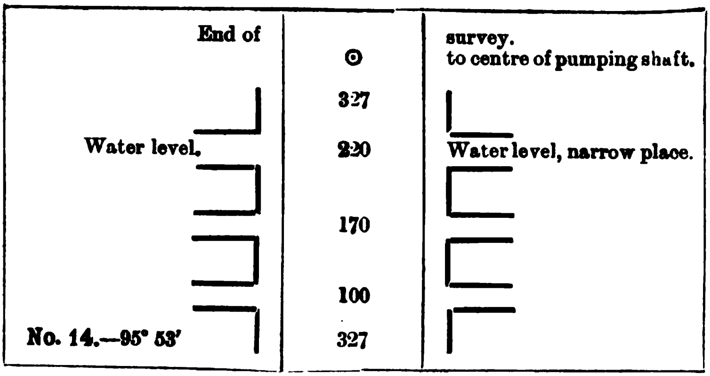


to permanent mark left some 20 years ago.

35 yds. to rise hitch.

30 yds. to rise hitch.

No. 11.—251° 16′



End of	⊙	survey. to centre of pumping shaft.
	327	
Water level.	220	Water level, narrow place.
	170	
	100	
No. 14.—95° 53′	327	

The angles taken in the survey given are reduced to angles from the magnetic meridian in the following manner:—

The vernier angles for lines 1 and 2 represent the respective magnetic azimuths for these lines.

No. 1 mag. azth., 340° 00′+3rd angle 138° 20′=478° 20′
478° 20′−180° 00′=298° 20′=**No. 3 mag. azth.**
No. 3 mag. azth., 298° 20′+4th angle 131° 15′=429° 35′
429° 35′−180° 00′=249° 35′=**No. 4 mag. azth.**
No. 4 mag. azth., 249° 35′+5th angle 273° 21′=522° 56′
522° 56′−180° 00′=342° 56′=**No. 5 mag. azth.**
342° 56′+ 89° 07′=432° 03′;
432° 03′−180° 00′=252° 03′=**No. 6.**
252° 03′+ 87° 20′=339° 23′;
339° 23′−180° 00′=159° 23′=**No. 7.**
159° 23′+255° 32′=414° 55′;
414° 55′−180° 00′=234° 55′=**No. 8.**
234° 55′+ 93° 00′=327° 55′;
327° 55′−180° 00′=147° 55′=**No. 9.**
147° 55′+ 94° 15′=242° 10′;
242° 10′−180° 00′= 62° 10′=**No. 10.**
62° 10′+251° 16′=313° 26′;
313° 26′−180° 00′=133° 26′=**No. 11.**
133° 26′+131° 22′=264° 48′;
264° 48′−180° 00′= 84° 48′=**No. 12.**
84° 48′+273° 20′=358° 08′;
358° 08′−180° 00′=178° 08′=**No. 13.**
178° 08′+ 95° 53′=274° 01′;
274° 01′−180° 00′= 94° 01′=**No. 14**

It is advisable to take check loose-needle readings during the course of the survey, and if equal care be taken to select points free from local magnetic disturbance for this purpose, these check readings may be used to correct small errors in the fixed-needle work. Care must be always taken in measuring magnetic azimuths direct off the meridian to obtain the azimuth of the line under consideration, in its normal direction in the traverse. This is particularly the case at intermediate stations when taking the magnetic azimuths of the lines on either side of the station. The needle and the vernier clamps are free, and the body-clamp tight, until both azimuths have been measured; and in taking that of the line behind the station occupied, a back-sight is taken, whilst for the line which is forward from the station a fore-sight is taken. In the continuous-reading method, after the back-sight has been taken at any station free from magnetic disturbance, if the needle be set free it should come to rest with the north end at the zero of the graduations in the case of the inside vernier dial, whilst with an outside vernier dial the needle and vernier readings should be identical. This check, however, is not complete, as it is only a proof of the purely manipulative part of the angular observations, and does not reveal errors in taking the readings or in entering them up. The details of an actual survey, made by the continuous-reading method off the magnetic meridian, by Mr. W. F. Howard,* may be quoted. The survey was made between the Speedwell and Netherthorpe shafts at Staveley, with the intention of effecting a holing into the latter. The straight distance between the shafts, measured direct on the surface, was 31·13 chains, and the distance between the shafts by the underground roads was 35·43 chains, making the total circuit 66·56 chains, and requiring 16 sets underground. The foregoing is a copy of the survey notes.

The survey was made with a 5-inch Davis dial, divided to half-degrees, with a vernier reading to 3 minutes.

In this instance, the magnetic bearing and the horizontal distance sought, from the face of the heading to the intended upcast shaft, was calculated to be N. 58° 38′ E., 190·5 links. It was then determined to drive direct into the shaft, and the draft was accordingly set out at the above bearing; and the holing proved this bearing and the calculated distance to be absolutely correct.

In this particular case it will be noted that quadrant bearings were read direct. The advisability of this procedure is very much open to question for the reasons already given (p. 84), and in the case of readings with the vernier they apply with still more force.

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* *Trans. N. Engl. Inst. M.E.*, vol xx., 1870, p. 31.

No.	Vernier Bearing.	Horizontal Distance.	Remarks.
		Links.	
1	N. 34° 24′ W.	13½	From Speedwell north or down-cast shaft.
2	N. 58° 35′ E.	639	.. ..
3	N. 45° 41′ E.	274	.. ..
4	N. 37° 29′ E.	130	.. ..
5	N. 8° 40′ W.	127	.. ..
6	N. 15° 02′ E.	405	.. ..
7	N. 17° 57′ E.	206	.. ..
8	N. 11° 35′ E.	158	.. ..
9	N. 35° 37′ W.	73	.. ..
10	N. 18° 20′ E.	260	.. ..
11	N. 18° 14′ E.	470	.. ..
12	N. 69° 42′ E.	384	.. ..
13	S. 27° 45′ E.	63	.. ..
14	N. 69° 32′ E.	73	.. ..
15	N. 71° 57′ E.	78	To face of main ventilating drift intended to hole into Netherthorpe shaft.

It is not always possible or, at any rate, convenient to start a traverse at a point free from local magnetic disturbance, and in such a case, if it is desired to use the magnetic meridian as the reference line, the magnetic azimuth of one or other of the intermediate lines is measured and used to determine the magnetic azimuths of the remaining lines. The survey is carried on exactly as if the first line was to be used as the line of reference until a

No.	Assumed Azimuth.	Correct Bearings.	Distance.			Remarks.
			Fms.	Ft.	In.	
1	0° 00′	..	10	4	9	From ⊙ 2 ft. W. of centre shaft.
2	275° 06′	..	7	3	2	..
3	282° 12′	..	8	1	9	..
4	278° 51′	..	7	3	0	..
5	286° 00′	277° 09′	3	5	9	..
6	292° 00′	283° 09′	9	2	9	..
7	296° 00′	..	9	5	10	END.

station is reached where a magnetic azimuth can conveniently be measured; and from thence forward, if the continuous-reading method is being used, the magnetic azimuths can be read, or as an alternative the survey can be completed as it was started, and all the magnetic azimuths determined afterwards. The foregoing notes represent a traverse made by the continuous-reading method in the manner described. The angles given in the column headed Assumed Azimuths are the actual vernier readings. The magnetic azimuths of lines 5 and 6 were measured in addition.

It will be evident in the above notes that if the traverse had been started off the magnetic azimuth of the first line, the vernier reading of line 5 would have been the correct magnetic azimuth. As, however, the azimuth of line 1 was assumed to be zero, its magnetic azimuth can be found by subtracting the assumed azimuth of line 5 from its magnetic azimuth, thus :—

$$(277° \, 09' + 360°) - 286° \, 00' = 351° \, 09' = \text{magnetic azimuth of line 1.}$$

The addition of the 360° is necessary in this case, as the assumed azimuth has a larger numerical value than the magnetic azimuth, and it is essential that the subtraction be made in the way indicated, otherwise the normal magnetic azimuth is not obtained. The same result can be obtained in the above case from line 6, thus :—

$$(283° \, 09' + 360°) - 292° \, 00' = 351° \, 09'.$$

The magnetic azimuths of the remaining lines of the traverse are found by adding that of the first line to the assumed azimuth of each of the others.

Normal Azimuths in Fixed-Needle Traversing.—In dealing so far with the methods of traversing and of calculating azimuths, it has been assumed that the observations have been taken with a dial in which the vernier circle has been graduated in the normal direction (see Chapter IV.), and that the magnetic azimuths obtained, whether assumed or magnetic, are normal. As was pointed out in Chapter IX., in many vernier dials the vernier readings are taken on a circle graduated in a contra-clockwise direction, such dials being often spoken of as *left-handed*. The direction of graduation in no way affects the method of making the observations, but naturally the readings are affected and the treatment of the vernier angles obtained when a dial of the latter type has been employed has now to be considered. The angles may be treated according to the rules already given, and the azimuths so obtained used for plotting the survey by means of a protractor graduated in a contra-clockwise direction This, however, may subsequently cause confusion in comparing the survey notes with those of a survey of the same course made with a different type of instrument.

A better method is to convert all readings actually taken with the vernier into readings that would have been obtained on a normally graduated circle. This is done by subtracting each vernier reading from 360°. The converted readings are substituted for the observed readings in following out the rules previously given for determining azimuths. This method of dealing with the readings applies to a traverse made by any of the methods described, whether made off an assumed meridian or the magnetic meridian.

In the case of traverses made by the double fore-sight and the back- and fore-sight methods, normal azimuths are obtained if, instead of summing the azimuths and vernier angles, the latter are *subtracted* from the former. Taking the traverse used as an example of the double fore-sight method given on p. 156, if the angles had been read on a circle graduated in a contra-clockwise direction, the notes would have been as follows :—

Lines.	Distance.	Vernier Readings.	Assumed Azimuth.
	Links.		
1	474	..	0° 00′
2	452	124° 12′	55° 48′
3	253	245° 15′	350° 33′
4	457	104° 30′	66° 03′
5	448	73° 27′	172° 36′

The azimuths recorded, which are normal, are obtained thus :—

$$
\begin{aligned}
(360° + 0° - 124° 12') - 180° &= 55° 48' \\
(360° + 55° 48' - 245° 15') + 180° &= 350° 33' \\
(350° 33' - 104° 30') - 180° &= 66° 03' \\
(360° + 66° 03' - 73° 27') - 180° &= 172° 36'
\end{aligned}
$$

In calculating the azimuths of lines 2, 3, and 5, the assumed azimuths of lines 1, 2, and 4 being less than the vernier angles from which they have to be subtracted respectively, require the addition of 360° to each, as shown.

Measuring Vertical Angles with the Vernier Dial.—The vernier dial is provided with a graduated circle or, more usually, graduated sector for this purpose, and its use becomes necessary when the lines of the traverse cannot be measured horizontally and the horizontal distances have to be computed from the measurements taken on a slope. Vertical angles can, of course, be applied to the determination of differences of level, but this application can be left out of account as far as the dial is concerned. The taking of vertical angles with the necessary degree of accuracy for the computation of horizontal distances for ordinary purposes is a comparatively simple matter. They are usually taken after a sight has been taken along a line in connection with the measurement of the horizontal angle in the traverse, and in describing the procedure it is taken for granted that the instrument has been set up and levelled at one of the stations. Special sights are provided on the sight-vanes for taking vertical angles. These consist of a pin-hole on one vane opposite to a circular window on the other vane. The circular window has a pair of cross-hairs, and the line formed by the pin-hole and the intersection of the cross-hairs is parallel to the plane of the horizontal graduated circle when the swinging arc carrying the sight-vanes is in its normal position. In this position also the vernier for reading the vertical angles should be at zero. Two such lines of sight are provided so that observations can be taken from either sight-vane. In taking a vertical angle the swinging arc is released if it has not been in use before and set approximately at the angle of slope, the height of the line of sight that will be used in making the observation is measured by means of a tape, and a signal flame is set exactly at this height above the station at the other end of the line in the traverse. This setting can be readily performed by suspending a lamp from the roof. The eye of the observer is then placed at the pin-hole and the horizontal hair in the window opposite is brought to bisect the flame. The reading of the vernier indicates the angle that the line of the traverse makes with the horizontal plane. When three tripods are being used, it is not usual to measure the height of the line of sight above the station, the flame of the signal lamp being sighted without its height being adjusted. The vertical angle of each line is measured from both ends, and the mean value taken. The accuracy necessary in the measurement of the vertical angles increases with the magnitude of the angles.

Permanent Marks.—In making underground surveys, which will subsequently be extended, it is necessary that marks be left at the furthest convenient points inbye, from which to start the later surveys. If the surveys are being made on a magnetic basis, a single mark will serve from which to start the extension survey, but if any other line of reference is being used, then two marks at least must be left from which to establish the direction. In the latter case they may conveniently be at the two ends of one line of the traverse, the azimuth of this being known from the first survey. It can be used as the basis of the extension survey. The two permanent marks may be at widely separated stations in the traverse, and made to form the starting and closing points respectively of the extension survey. In collieries where the movements of the strata are often such that the direction given by two marks on one line cannot be relied on after the lapse of a very short time, unless the line is very long, the second method of marking the two points is advisable, but it involves a considerable amount of extra work in calculating the azimuths. The difficulty in connection with the marking of directions of lines from which to extend fixed-needle surveys is probably one of the principal reasons why the magnetic meridian, the use of which has many obvious drawbacks, is used to such a great extent in colliery work. In metal-mining there is usually no difficulty of this nature, and surveys can be continued from even comparatively short lines if the marks have originally been put in with sufficient accuracy.

Checking of Traverse Surveys.—A traverse survey should always be made in such a way that a check on the observation as a whole is available apart from any check obtained by duplicating the several operations involved.

Closing the Traverse.—The most satisfactory check is obtained if the lines are arranged to form a complete circuit, the starting and finishing points being identical. A traverse can always be closed, although sometimes it may mean returning along the same roads, and usually in the latter case the position of the stations can be slightly varied so that the surveyor will not be biassed by the results obtained on his outward journey.

On plotting a closed traverse, if the starting and finishing points coincide it may reasonably be considered that all the measurements involved, whether of distances or directions, are correct. The possibility of compensating errors existing must, however, not be lost sight of, and when the importance of the survey warrants such a proceeding, it should be repeated even if it is proved to close correctly. The failure of a traverse to close may in some of the methods of plotting be due to errors in the plotting itself, but this can be neglected for the present, as the accuracy of the survey itself can be determined independently of the plotting by calculation of the co-ordinates of the various stations.

Failure to close may be due to errors in the measurements of either the distances or the directions, or to errors in the measurements of both. If the survey has been made by either the back- and fore-sight or double fore-sight methods, and a closing angle taken between the last and first lines, it is possible to check the accuracy of the angular measurements independently of the distances, and if the closing error is outside the permissible limits, the repetition of the angular observations may be avoided if these can be proved to be correct.

The measurement of the closing angle referred to enables a value for the azimuth of the first line to be obtained which is dependent on the value of all the angular observations in the traverse. The azimuths of the lines being obtained progressively, the value of each is dependent on the vernier readings taken, so that by adding the reading of the closing angle to the azimuth of the last line the aggregate error of the angular measurements is determined, being represented by the difference between the assumed or known value and the calculated value of the azimuth of the first line.

If the closed traverse forms a single polygon, as is usually though not invariably the case, another method is available for determining the aggregate error in the angular measurements, providing that these have been made by either of the methods recently referred to, and that the closing angle has been observed. It depends upon the fact that the internal angles in a polygon are equal to twice as many right angles as the polygon has sides, less four right angles. The angles read are not always the internal angles of the polygon formed by the traverse, but depend upon the direction of graduation in the instrument used, on the general direction of the traverse, and on the particular method of traversing which is employed. As the calculations of the internal angles from the observed vernier readings in some cases would be too laborious to render the method useful in practice, the following formulæ, deduced from the above property of a polygon, may be used. They cover all the cases comprised by the above conditions. The first four apply when the dial graduation is clockwise, and the last four when it is contra-clockwise. In all the formulæ S represents the sum of the observed vernier readings and n the number of lines in the traverse.

Method of Traversing.	General Direction of Traverse.	Formula.
Graduation Clockwise—		
Double fore-sight,	Clockwise	$S = n180^\circ + 360^\circ$
,, ,,	Contra-clockwise	$S = n180^\circ - 360^\circ$
Back- and fore-sight,	Clockwise	$S = 360^\circ$
,, ,,	Contra-clockwise	$n360^\circ - S = 360^\circ$
Graduation Contra-clockwise—		
Double fore-sight,	Clockwise	$S = n180^\circ - 360^\circ$
,, ,,	Contra-clockwise	$S = n180^\circ + 360^\circ$
Back- and fore-sight,	Clockwise	$n360^\circ - S = 360^\circ$
,, ,,	Contra-clockwise	$S = 360^\circ$

In the case of the continuous-reading method, in starting the survey the azimuth of the first line must be known or assumed, and the vernier clamped at the corresponding reading, before the first back-sight is taken. If at the end of the survey the first station be occupied and the azimuth of the first line measured by an observation involving the last line, it should agree with the azimuth with which the traverse was started, provided the manipulation of the instrument has been correct throughout. Such an agreement does not constitute a check on the readings entered for the intermediate azimuths, and, as a matter of fact, it is impossible to obtain a satisfactory check on the angles, which is independent of the distances, and in the event of a closing error being revealed which is outside the permissible limits, there is no alternative to repeating the entire survey.

Checking of Open Traverses.—If the traverse is not closed no complete check on the observations as a whole is available. The angular work can be checked if the azimuths of the first and last lines can be measured direct. At the surface it is possible to measure the true azimuths of both these lines by astronomical observations, or the magnetic azimuths can both be observed, but underground the measurement of the former is out of the question. In addition to measuring the azimuths, the angles between each successive pair of lines must be measured independently. Thus, in traversing with either the double fore-sight or the back- and fore-sight methods, if the magnetic azimuths are measured by means of the needle, starting with the observed azimuth of the first line and successively calculating the azimuths of the remaining lines, the calculated value for the last line depends upon all the vernier readings, and this should agree with the direct reading observed.

In connection with the continuous reading method carried out off the magnetic meridian, it has already been pointed out (p. 163) that a check on the manipulative work only can be obtained by using the needle at intermediate stations.

Traversing with the Theodolite.—There is no difference in principle between the methods of traversing with a theodolite and those employed with the vernier dial, and we have only to consider the modifications necessitated by constructional differences in the two instruments.

Owing to superiority in design and workmanship, the theodolite is essentially an instrument of considerably greater precision than the dial, but in order to take full advantage of this to increase the accuracy in traversing, all the operations involved must be carried out with increased accuracy, and the methods of performing them to attain this will now be described.

Centring and Levelling-up. — These operations have already been described, but more particularly with reference to setting a theodolite over a station mark on the floor. In underground work it is generally more convenient to work from overhead marks. These must be of such a nature that they permit of centring with great accuracy. A nail knocked into one of the timbering bars, as shown in Fig. 74, forms a mark sufficiently accurate unless the lines are exceptionally short. Spuds of various forms are very largely used for marking stations, and the form shown in Fig. 75, which is about half the natural size, is very convenient, and can be readily made by flattening out a horse-shoe nail and punching or drilling a small hole in the flat. Horse-shoe nails being usually considerably longer than is convenient for spuds, they are usually cut short and repointed. Spuds may be knocked into the timbering bars or in the case of this not being convenient, short holes (3 or 4 inches in depth) may be drilled into the roof and the hole plugged with a wooden

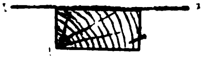
Fig. 74.

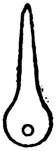
Fig. 75.

peg and the spud inserted in the latter. It will generally be found most convenient to attach a loop of string to the mark and suspend the plummet from this, instead of suspending direct from the nail or spud; this is particularly the case when the roof is high. It is necessary to adjust the height of the plummet very exactly, and special forms of buttons are supplied for this purpose, but some form of hitch will generally be found more convenient for overhead stations. Two of these hitches are shown in Fig. 76, the one on the right being a slip form. That on the left is not a slip-hitch, but is very quickly made and unmade, and permits of very accurate setting. Either form will support the weight of an ordinary theodolite plummet, weighing from 4 to 6 ozs., but if a much heavier plummet is used it is safer to combine the two, making the slip-hitch first and the other one below.

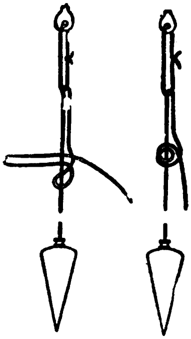
Fig. 76.

The height of the plummet is adjusted approximately before the instrument is placed under the station and adjusted accurately with the point just clearing the pop-mark after levelling and rough-centring. It has been stated already that for fine centring some form of shifting head is a necessity, and rough-centring is performed by manipulating the legs of the tripod until the range of the centring device on the instrument has been attained. The instrument is then levelled with the plate levels, and the telescope brought into a horizontal position and the bubble of its spirit-level centred. The centring is completed by moving the shifting head. If the latter is above the foot screws, the final centring does not disturb the levelling, but otherwise the final levelling and centring may have to be repeated two or three times.

Signals and Sighting.—The signals used in underground work may be lamps with central wicks—*e.g.*, safety-lamps, or a plumb-line. For distances above, say, 100 feet the flame of a safety-lamp is quite suitable, and if the wick tube is circular, it may be safely used for much shorter lines. Generally speaking, for short lines it is advisable to sight a string to which a plummet is attached. The string can be made clearly visible by holding a piece of tracing paper behind it and a lamp behind the paper, or a piece of ordinary paper may be used and illuminated by a lamp held a little to one side, but between the string and the paper, the object being to throw the string into as great relief as possible without producing a shadow which might be mistaken for the string itself.

If the flame of a lamp is being sighted it is necessary to illuminate the cross wires of the telescope. This can be done by holding a lamp to one side of the object-glass and slightly in front so that some light is reflected down the tube of the telescope through the object-glass, in such a way that, at the same time, the object can be sighted without hinderance. For illuminating the cross-wires a ring is sometimes fitted on to the object-end of the telescope. To the ring is fixed at an angle of 45° a piece of brass, silver-plated on the under side, with an elliptical hole in the centre. The optical axis of the telescope thus passes approximately through the centre of the hole in the reflector. Two forms of reflector are shown in Fig. 77. In one case there is an elliptical hole, in the other there is a small ellipse of metal. A light held near the reflecting surface illuminates the cross-wires. Satisfactory results can be obtained when the reflector is made of white cardboard. A small silver ball attached by a wire also answers well. For illuminating the cross-wires very little light is required. The elliptical hole of the one reflector must, therefore, not be too small, nor the small ellipse of the other too large. In the theodolites made by Messrs. Troughton and Simms, the cross-wires are illuminated by means of a hole drilled in the supports, and a small mirror placed at an angle of 45°, in the axis of the telescope. The light is held near the supports, instead of near the object-glass.

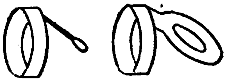

Fig. 77.

An explanation of some of the terms used in connection with theodolite observations will assist in describing the latter. *Turning in azimuth* consists in rotating the limb together with the vernier plate and all its attachments, standards, telescope, etc., or in rotating the vernier plate and the attachments, the limb remaining stationary. *Turning in altitude* consists in turning the telescope, together with the vertical circle, in a vertical plane, the limb and vernier plate remaining stationary. *Transiting the telescope* consists in turning the telescope in a vertical plane until it is pointing in a direction opposite to a previous direction, the limb and vernier plate remaining stationary. The operation of transiting is sometimes referred to as *plunging the telescope* and again as *turning the telescope through*.

In taking a sight with a telescope the instrument is turned in azimuth until the telescope is pointing in the direction of the signal; a rough alignment made by sighting along the top of the telescope barrel will generally enable the signal to be brought at once into view when the eye is placed at the eye-piece and the telescope turned in altitude. It is brought approximately into the centre of the field, and the limb and telescope are then both clamped. The fine adjustment to make the cross-wires bisect the signal accurately is performed by means of the tangent screws provided for the purpose. On the first sight taken it will be necessary to adjust for parallax, but subsequently it should only be necessary to turn the milled head of the focussing screw in order to obtain a sharp image of the signal.

Three-Tripod System.—This system is also applied to traversing with the theodolite, and where the instrument is in general use for the underground work of a mine a great saving of time can be effected. The outfit required for obtaining under all conditions equal accuracy to that obtainable when working carefully with a single tripod is fairly expensive, as each tripod must be supplied with a head carrying levelling screws and spirit-levels, the sensitiveness and accuracy of the latter being equal to that of the plate levels of the theodolite. It is not necessary or even advisable to provide shifting heads on all three tripods, only one of the latter being so provided for convenience in setting up at the starting point, and also for general use when the three tripods are not being used.

Measuring Distances.—This part of the work must also be carried out with greater accuracy than is consistent with traversing with a dial, and the use of a steel band is advisable. The station marks should be transferred to the floor by means of plummets, and if distances greater than the length of the band are to be measured, alignment should be made with the telescope and each length accurately marked on a flat stone or on a sleeper. Steel bands of 200 feet or two chains in length and about ½ inch in width, are obtainable, and greatly facilitate measurements. Considerably longer bands are obtainable for surface work, but the lengths given above are not often exceeded for underground work.

Vertical Angles.—The theodolite enables vertical angles to be measured with such accuracy that differences of level can be computed from them with sufficient accuracy for most purposes for which they are required, and hence it is not unusual to take vertical angles for all the lines in the traverse, even when the inclinations are too slight to affect appreciably the distances. The method of observing the angles is very much the same as with the vernier dial, greater care, however, being necessary in the levelling of the instrument, and the setting of the signal to the exact height of the instrument must be very carefully performed. In the case of the theodolite the height for the signal corresponds to that of the horizontal axis of the instrument, and in sighting, the centre horizontal cross-wire is brought to bisect the signal.

Magnetic Observations.—These are practically always taken with the aid of the vernier, and if the compass is of the trough pattern it is impossible to obtain readings otherwise, and even with a round compass-box the reading of the needle with any degree of accuracy is quite impossible in some positions owing to the standards. In observing the magnetic azimuth of a line the instrument is set up at the starting station, and after centring and levelling, the vernier is set to zero and the needle is unclamped. The body clamp is released and the instrument turned in azimuth until the north end of the needle coincides with the zero of the compass-ring, or in the case of the trough-compass, with the centre division of the scale at the north end of the box. The telescope should now be pointing towards the north. The vernier clamp of the horizontal circle is released, and the instrument turned in azimuth and the cross-wires brought to bisect a signal at the finishing station of the line. The reading of the vernier now indicates the magnetic azimuth of the line. If the magnetic azimuth is being observed from the finishing station to the starting, the telescope should be transited before the observation is made, so that it points south, or the vernier reading may be transposed by the addition or subtraction of 180°.

Methods of Traversing.—Any method of fixed-needle traversing that can be carried out with the vernier dial can also be adopted with a transit theodolite. For ordinary work it is not necessary to read the two verniers, which should be distinctly marked either by letters or figures, and one vernier taken as the standard.

Double Fore-sight Method.—This is considered first, as being the most commonly used and the most accurate method, and it is also the only one that can be conveniently used with a plain theodolite. The first setting of the instrument is made at the second station, unless the survey is being carried out off the magnetic azimuth. After the centring and levelling have been performed the vernier is set to zero and the vernier clamp left tight. The body clamp is released, and the instrument is turned in azimuth until the telescope is pointing towards the first station, the body clamp is tightened, and using the tangent screw attached to the latter, the cross-wires are brought to bisect the signal. The vernier clamp is released and the instrument turned in azimuth until the telescope is pointing towards the third station, the vernier clamp is tightened, and using the tangent screw attached to the latter clamp, the cross-wires are brought to bisect the signal. The vernier is read and booked. A check sight is then taken on to the first station by releasing the vernier clamp, turning in azimuth, and using the tangent screw attached to the vernier clamp in order to obtain the bisection of the signal with the cross-wires. This should bring the vernier to zero if the manipulation of the instrument has been correct. Each of the remaining stations is occupied by the instrument, and the procedure at each is identical with that described. It is to be noted that in this method the telescope is not transited.

The following is an example of the survey of a closed polygon by this method:—

No. of Line.	Horizontal Angles.	Magnetic Azimuths.	Measured Distance.
			Links.
Mag. mer.	0° 00′	0° 00′	..
1 off mag. mer.	121° 27′	121° 27′	1091
2 „ 1	97° 36′	39° 03′	252
3 „ 2	209° 01′	68° 04′	196
4 „ 3	159° 40′	47° 44′	534
5 „ 4	195° 32′	63° 16′	384
6 „ 5	85° 31′	328° 47′	336
7 „ 6	152° 07′	300° 54′	1055
8 „ 7	103° 34′	224° 28′	771
9 „ 8	104° 03′	148° 31′	154
10 „ 9	262° 58′	231° 29′	605
1 „ 10	69° 58′	121° 27′	proof line.

Back- and Fore-sight Method.—As in the previous method, the instrument is set up first at the second station, and after centring and levelling the vernier is set to zero. The body clamp being free, the limb is turned until the telescope is pointing towards the signal at the first station, the body clamp is tightened, and with the tangent screw attached to it, the cross-wires are brought to bisect the signal. The vernier clamp is released and the telescope is transited, the instrument is turned in azimuth until the telescope is pointing towards the signal at the third station, the vernier clamp is tightened, and using the tangent screw attached to it, the cross-wires are brought to bisect the signal, the reading of the vernier is taken and booked. A check observation is taken on to the first station by releasing the vernier clamp, transiting the telescope and turning in azimuth until the telescope is pointing towards the signal, and the bisection obtained with the aid of the tangent screw attached to the vernier clamp after the latter has been tightened. The procedure at all the remaining stations is identical.

Calculation of Azimuths.—The vernier angles obtained in the above methods correspond exactly with those obtained in the corresponding method with the vernier dial, as do also the methods of calculating the azimuths (see pp. 154 and 156).

Continuous-Reading Method.—The procedure in this method only differs from that in the back- and fore-sight method in that it is not usual to take the check observation on to the back station, and instead of setting the vernier to zero before taking the back-sight, the sighting is performed with the vernier at the same reading as was obtained on the fore-sight at the previous station.

This method, as practised in the mines of the Pennsylvania Railroad, has been fully described by Mr. R. van A. Norris.* The surveying party consists of a theodolite-man, station-man, back-sight, fore-sight, and chain-man, with a fireman to attend to the safety of the party. Three tripods are used, but the wicks of the tripod lamps, which were found too large for accurate sighting, are replaced by steel wire one-sixteenth of an inch in diameter and three-eights of an inch in height. The sights are taken to the bottom of this wire, and measurements are taken along the line of sight with a 300-foot steel tape, marked at every 5 feet.

Continuous azimuth angles are run, and the entries in the note-book consist of the vernier reading on a continuous graduation from 0° to 360°, and the quadrant reading or course. A needle reading is taken roughly with a view to detect serious errors. At the commencement of the survey, the vernier is set to the course of the first line taken from the notes of a previous survey. The error in a closed survey of fifteen or more lines is rarely found to exceed three minutes. For levelling purposes, the vertical angles are read very carefully, the sight-wire being so arranged that it is just 0·5 foot below the centre of the instrument. The method of booking adopted is shown on the next page. The error on

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* *School of Mines Quarterly*, vol. xi., 1890, p. 328.

EXAMPLE OF MR. NORRIS'S METHOD OF BOOKING COLLIERY-SURVEYS.

May 1, 1889. *Continuation of Survey of No.* 3 *Plane.*

STATIONS.	COURSES.			DISTANCES.			ELEVATIONS.			REMARKS.
	Needle.	Angle.	Course.	Vertical Angle.	Tape.	Hor. Dist.	Ht. Inst.	Staff.	Elevation.	Vertical Distance.
1–2	..	..	N. 85° 24′ E.	..	..	..	−1·54	..	+233·89	..
2–3	S. 4° E.	173·46	S. 6° 14′ E.	−6° 00′	57·60	57·28	..	+1·90	+228·32	−6·02
3–*x*	N. 82° W.	..	N. 83° 50′ W.	..	68·00	..	..	..	..	Face
3–4	N. 85½° E.	84·21	N. 84° 21′ E.	−2° 56′	22·76	22·73	..	+2·25	+228·01	−1·16
4–5	S. 8° E.	170·45	S. 9° 15′ E.	−5° 46′	52·10	51·83	..	+2·05	+223·08	−5·23
5–6	S. 88° E.	91·24	S. 88° 36′ E.	−3° 07′	27·64	27·60	..	+1·85	+221·88	−1·50
6–*x*	N. 87° E.	..	N. 85° 30′ E.	−2° 15′	106·00	105·92	..	..	..	..
6–7	S. 4½° E.	174·20	S. 5° 40′ E.	−5° 56′	52·58	52·30	..	+1·85	+216·95	−5·43
7–*x*	N. 85° W.	..	N. 86° 50′ W.	+1° 30′	86·00	..	..	..	..	Face.
7–8	N. 86° E.	84·59	N. 84° 59′ E.	−3° 42′	25·19	25·13	..	+2·10	+216·08	−1·62
8–9	S. 1° E.	177·33	S. 2° 27′ E.	−4° 00′	34·37	34·28	..	+0·90	+212·39	−2·39
9–10	S. 73° E.	107·50	S. 72° 10′ E.	−5° 29′	99·96	99·50	..	+1·90	+204·94	−9·55
10–8	N. 81° E.	80·12	N. 80° 12′ E.	−4° 01′	50·00	49·87	..	+1·10	+201·14	−3·50
8–7	..	..	N. 78° 55′ E.	..	..	..	..	..	..	..

closing this survey is one minute. The horizontal distances, elevations, and vertical distances are calculated in the office; and the column headed " staff " gives the distance from the centre of the instrument to the station in the roof. With this method of surveying, it is possible to attain great speed, from forty to fifty stations being considered a fair night's work. All main stations are plotted from calculated latitudes and departures (see Chapter XIII.), and the stations in the workings are filled in with the aid of the protractor.

Elimination of Errors in Adjustments.—For precise work, the effects of the errors in the adjustments of the theodolite must be taken into account, and it may be said at once that the double fore-sight method has a distinct advantage over the methods which involve transiting of the telescope, in that when the lines of the traverse are all nearly horizontal and the distances all more or less equal, the errors in the adjustments produce no appreciable errors in the measurements of the horizontal angles, and under any circumstances the effects of the errors are always the least in this method. In any method involving transiting of the telescope an error is introduced in the measurement of each of the horizontal angles, which, generally speaking, is equal to twice the error of the adjustment for collimation. The effects of the errors in the adjustments can be entirely eliminated in any of the methods by taking, at each station, two observations of the horizontal angle, between each of which the telescope is reversed with regard to the horizontal axis. The mean of the two observations is taken as the value of the angle.

The reversal of the telescope with regard to the horizontal axis may be effected either by removing the telescope bodily from its supports on the standards and replacing with the ends of the axis interchanged, or the telescope may be transited and the instrument turned in azimuth. One effect of the reversal of the telescope is to change the relative position of the vertical circle with reference to the telescope, the circle being in one case on the right-hand side of the telescope, and in the other on the left. This has given rise to the expressions *face-right* and *face-left* in connection with theodolite observations.

For important surveys it is advisable, even if the instrument is in good adjustment, to work by the double fore-sight method and take face right and face left observations at each station, and to read both verniers. The mean of the four values obtained for the angle is used in calculating the azimuths.

Comparison of the Theodolite and Compass.—In making a comparison between these instruments, a number of considerations have to be taken into account. The principal difficulties in connection with the use of the compass arise from the variations to which the magnetic meridian is liable. Thus, the daily variation of the declination of the needle is nearly 10 minutes; disregarding the occasional irregular perturbations of the needle, it is obvious that errors of 10 minutes or more may occur in the period between 8 a.m. and 1 p.m., when the declination of the needle passes from its minimum to its maximum. With a radius of 100, the chord of 10′ is 0·29. Therefore, from the change in the direction of the needle, there will be in a length of 100 fathoms a lateral displacement of nearly three-tenths of a fathom.

The uncertainty of the readings of the compass is also a disadvantage. With compasses of the ordinary size, the needle cannot be read more accurately than to one-fifth of a degree. Thus, errors of one-tenth of a degree, or 6 minutes, are unavoidable. In a length of 100 fathoms, this error in the bearing gives a lateral error of 0·174 fathom.

Magnetic storms and the influence of ferriferous rock masses* in the neighbourhood may give rise to considerable error, which cannot be detected while the survey is in progress.

With the theodolite very different results are obtained. With a 6-inch instrument, the horizontal angle, even without repeating, may be determined accurately to 30 seconds. The chord of this angle being 0·000145, in a length of 100 fathoms, the lateral error will not exceed 0·0145 fathom. The accuracy of the theodolite for a single observation is thus 30 times as great as that of the compass.

The repetition of the angles not only ensures great accuracy, but is also a valuable check on the results. If, for example, an angle has been repeated four times, and if the second, third, and fourth observations give results closely approaching the result of the first observation multiplied by two, three, and four respectively, it is evident there can have been no serious error. With the compass, on the other hand, when a bearing is read repeatedly, the conditions remain the same, and it is quite possible to have exactly the same error each time.

In reading a bearing with the compass, the instrument must remain unmoved. The surveyor is, therefore, compelled to put his eye, his head, and sometimes his whole body into a particular position with reference to the instrument. With the theodolite, however, there is no necessity for such inconvenience, as the horizontal circle may be turned to any required position, without changing the angle indicated by the vernier. The results are, therefore, read with far greater precision.

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* See paper by Sir A. W. Rücker on "Regional Magnetic Disturbances." *Proc. Roy. Soc.*, vol. xlviii., p. 505, 1890.

One very strong point in favour of compass (loose-needle) surveying is that the errors in measuring directions are not cumulative, as in the case of fixed-needle traversing, where the determination of the successive azimuths depends upon the measurements of all the preceding angles, so that when the traverse involves a large number of lines, and especially if these are short, a loose-needle survey compares very favourably with a theodolite survey, provided that local disturbance of the magnetic meridian can be avoided.*

The theodolite of the usual size has the disadvantage of want of portability, its weight being a great drawback to its use underground. The telescope, too, cannot be used in mines when the air is bad from powder-smoke.

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* See *Effects of Errors in Surveying*, by H. Briggs, M.Sc., p. 94.

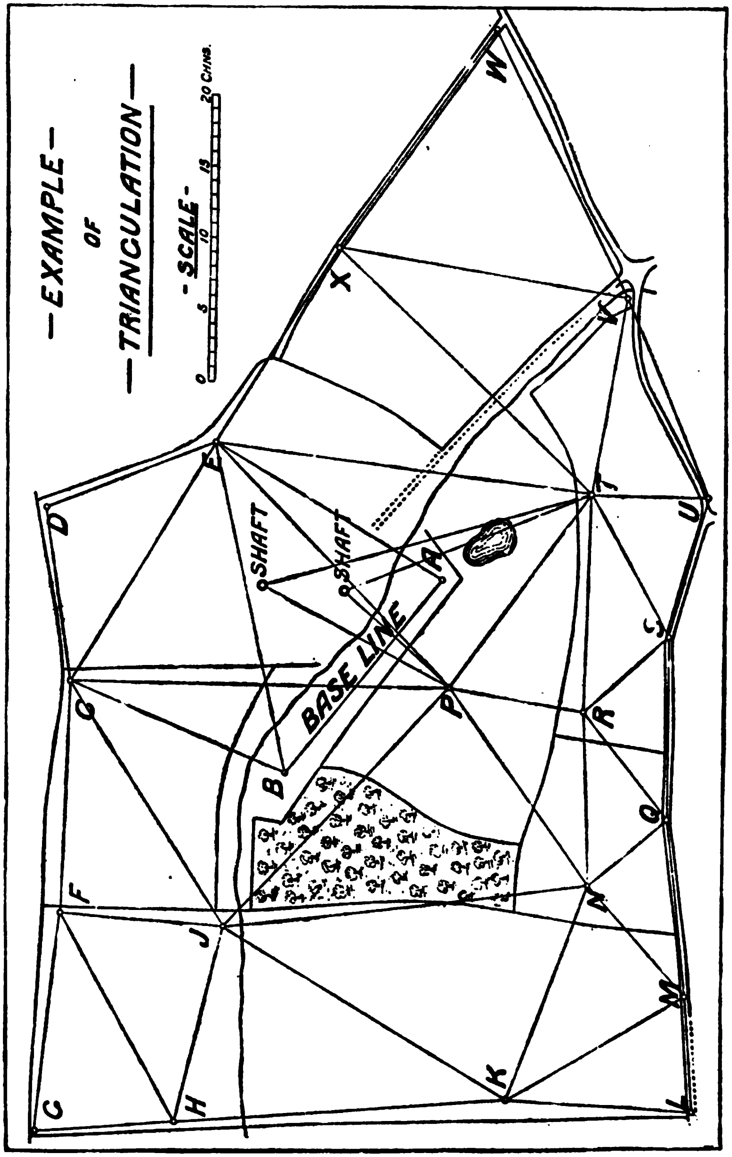
CHAPTER XII.

SURFACE-SURVEYING WITH THE THEODOLITE.

Methods Employed.—Traversing with the theodolite at the surface is very often employed as a complete method in connection with surveys of mine royalties. Any of the methods described in the previous chapter may be employed, traverses being run along the fences, roads, etc., and offsets taken from the traverse lines. More accurate results, however, can be obtained by triangulation, and this is especially the case in hilly districts.

Triangulation.—In this method of surveying, a number of stations are established at suitable points in the area to be surveyed, in such a way that when the points are joined up a network of imaginary triangles is formed, the outer lines of which follow approximately the boundary of the area as shown in the example on p. 183. After measuring the length of one side of one of the triangles and the angles at the corners of all the triangles, the lengths of all the remaining sides can be computed trigonometrically. By this means the positions of controlling points can be established all over the area, and the details filled in by measurements from them. The detailed measurements are obtained by traversing and offsetting, or by chain-surveying. In this country, where maps on a scale of 25 inches to the mile are available, much of the less important detail can be filled in from them.

Setting Out Triangulation Stations.—This portion of the work calls for considerable judgment. They should be chosen with a view principally to the formation of well-conditioned triangles, the ideal form being equilateral. In practice it is rare that even an approach to the equilateral form is possible for many of the triangles, and it is usually considered that a triangle is well-conditioned if the largest angle is less than 120° and the smallest greater than 30°. Very often triangles, which may be regarded as exterior to the main triangulation, are formed for the purpose of embracing the boundary, as in the case of the example shown


—EXAMPLE—
OF
—TRIANGULATION—
-SCALE-
0
5
10
15
20 CHNS.
W
X
V
T
U
S
R
Q
N
M
L
K
H
C
F
J
G
D
E
B
P
A
SHAFT
SHAFT
BASE LINE

in which the triangles to the south of the line KNRTV and in such cases the form of the triangles is less important and the limits mentioned above are sometimes encroached upon, particularly as regards the small angles. The stations should be chosen as far as possible so that when sighting from any given station, the *feet* of the signal poles under observation can be seen. Errors due to want of verticality of the poles are thus avoided. This condition can very often not be fulfilled, but it should always be the aim. In setting out the stations, it is a good plan to mark the usual height of the theodolite (when set up) on each of the poles by means of signal flags, and to make a practice of selecting the positions for the stations so that from any one of them these signal flags can be seen from the same height. It is occasionally necessary to erect elevated signals, but for triangulation schemes on the scale usual for mine-surveying purposes they can generally be avoided.

No general rules for the procedure in reconnaisance work can be given, as very probably no two surveyors, if working independently, would adopt the same scheme for any particular area. The whole of the ground should be carefully prospected, and any eminences, particularly on the lower-lying ground, should be examined as to their suitability for stations. A scheme can then be sketched out and the stations selected tentatively, but before definitely deciding on any exact point for a station, the surrounding stations must be approximately marked. A pair of good field-glasses are almost indispensable for the work, and it is advisable to carry some pocket instrument, such as a box-sextant or a prismatic compass, so that angles can be measured approximately with a view to keeping within the limits given above. The stations may be marked with stout pegs about 2½ inches square by 18 inches long, with a hole about ½ inch in diameter and about 3 inches in depth drilled in the top for the reception of the signal points. Lengths of iron tubing, such as gas-piping of a suitable diameter, for the reception of the poles, also form suitable station marks, especially for soft ground, but it is not advisable to use them where cattle are about, as the poles are so securely held that they are liable to be broken by the cattle rubbing against them, instead of simply being pushed over with practically no damage, as would be the case if they were inserted in a wooden peg. When the station marks are inserted, they should be driven in until the tops are flush with the ground, and when the survey has been completed the marks should be knocked in until they are a few inches below the ground, so that they are completely hidden and so preserved for use for future extensions of the survey.

Ordinary ranging poles about 6 feet long are, under ordinary atmospheric conditions, suitable for sighting up to about three-quarters of a mile, a distance which is not often exceeded in mine-surveying. Signal flags are of great assistance in picking the poles out when sighting, but in exposed situations they have a tendency to draw the poles out of the vertical, and in such cases flags placed on a pole a few feet away from the station may be used, the actual station being marked with an unflagged pole.

Base Lines.—The measured length from which all the remaining lengths in the triangulation are computed is called the base line, and must be determined with great accuracy, and usually the principal consideration in choosing the site for the base line is adaptability to accurate linear measurement. The principal requirement is an even surface, so that a steel tape will lie quite flat when subjected to a moderate tension. Though preferable, it is not essential that the surface be quite level, as in the case of sloping ground the vertical angle can be measured and the horizontal distance computed.

The measurement is generally effected by a steel tape, and for this work the graduations of the tape should start and finish at some little distance from the handles. A uniform tension should be maintained throughout the measurements; the tension at which the graduations are correct, or the correction to be applied for any given tension, can be ascertained from the makers of the tape. A tension of 15 to 20 lbs. will generally be found suitable. The tape should be compared with a standard tape before starting the measurement, and should be sent up to the makers for this purpose if a standard tape is not otherwise available. The uniform tension desirable can be most conveniently applied by attaching a spring balance to one of the handles of the tape and pulling from a ring on the balance until the correct tension is registered.

In measuring the base line for extensive triangulations, the effect of temperature on the length of the tape should not be lost sight of. A steel tape made in this country is usually correct at the average temperature (15° C. or 60° F.), and if the temperature at the time of measurement differs considerably from this a correction should be applied. As giving an approximate idea of the effects of temperature, it may be stated that a difference of temperature of 50° F. will cause a difference of about 1·7 feet in the measurement made with a steel tape of a line 1 mile in length. The variation with a tape made of invar alloy is very much less, and if such a tape is available the effects of temperature can usually be entirely disregarded for surveys of mine royalties.

Results which are very consistent and sufficiently accurate for most purposes can be obtained by the following procedure:—The theodolite is set up over one of the end stations on the base line, and a pole at the far station sighted; a number of pegs about 4 inches long by 8 inches square are ranged out at intervals slightly less than the length of the tape. A small wood screw with the nick at right angles to the line is driven into the centre of each peg. The exact distances between successive pegs is then measured by means of the tape, using a spring balance as already described. The vertical angle between successive pegs is measured by means of the theodolite and the horizontal equivalent of the separate distances computed; the total length of the base line is then obtained by adding the separate corrected lengths. The temperature at the time of measurement should be noted, and a correction applied if widely different from the standardisation temperature.*

The measurement should be repeated with the pegs in the same position and again after taking out the pegs and relining with the intervals slightly altered. Measurements taken on a day when the sky is overcast and the temperature variations are slight usually agree within one or two hundredths of a foot per 1,000 feet.

If the base-line has to be measured over rough ground of such a nature that the tape cannot be kept free from sag simply by tension, it must be supported at intermediate points. This can be done by driving stakes of a suitable length into the ground along the base-line and supporting the tape on fairly long nails driven sideways into the stakes at such a height that they form a straight line, which need not necessarily be level, provided that its vertical angle is measured. The centre of the stakes at each tape length must be exactly in the line and marked with a fine line or a screw head. The intermediate stakes are set slightly to one side. The intervals between the supporting stakes depend upon the tension applied, and on the thickness and width of the tape, and can rarely exceed 10 feet without it being necessary to apply a correction for the shortening due to sag.†

Special apparatus for the measurement of base-lines can also be obtained from a number of instrument-makers. The set comprises an accurate steel band usually made of invar alloy, and tripod stands for supporting the band, and also a means of maintaining a suitable tension. The outer tripods carry microscopes for setting and reading off the distances on the tape.

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* The coefficient of linear expansion for steel is ·0000066 per degree Fah.

† See paper by Professor Henry Louis, D.Sc., "On the Standardisation of Steel Tapes," *Trans. Inst. Min. Eng.*, 1902.

It is not essential that the base-line should form part of the main triangulation, which is arranged with a view to forming well-conditioned triangles throughout, whereas the position of the base-line is chosen principally with a view to accuracy in linear measurement. It may be connected by a subsidiary triangulation to the side most convenient, as shown in the example on p. 183, which represents a sketch of an actual triangulation carried out on a small portion of a metalliferous mine royalty in the county of Durham. The ground for the base-line was perfectly level and even. As will be seen, it was connected to the main triangulation through the triangles ABE and BCE, which are both exceptionally well-conditioned.

For the purpose of connecting a short base-line on to the main triangulation, and at the same time avoiding ill-conditioned triangles, the base-line may be prolonged by ranging lines in continuation of it, at one or both ends, until a suitable length is obtained. The lengths of the additional lines are calculated from angular measurements, as follows :—

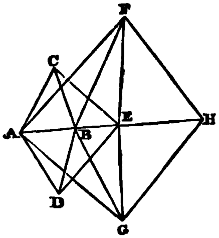

Fig. 78.

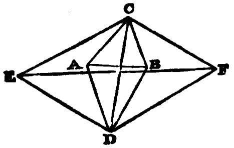

Fig. 79.

When the measured base, AB (Fig. 78), can be conveniently extended in one direction only, towards H, select a lateral station point, C, and a point E in the line ranged in continuation of AB, so that the resulting triangles, ABC and BCE, shall be well-conditioned, and if possible nearly equilateral. Measure all the angles of these two triangles, and calculate the length of the side BC, and by means of the side BC and the angles CEB, BCE, calculate the length of BE. Check the result by selecting another lateral station, D, on the opposite side of the base-line, and by solving the triangles, ABD, DBE. The length of the line BE is thus calculated from independent data. EH represents a further prolongation of the base-line, and F and G the lateral stations, which form the triangles, by means of which its length is calculated.

A comparatively short base-line may be connected with the sides of large triangles, without prolonging it and without introducing ill-conditioned triangles, by continually increasing the sides of the triangle, as shown in Fig. 79. AB is the measured base-line, and C and D are the nearest stations. In the triangles ABC, ABD, all the angles and the side AB being known, the other sides can be readily calculated. Then in each of the triangles DAC and DBC, two sides and the included angle being known, the length DC may be calculated in a variety of different ways which will check each other. Taking DC as a base-line, choose a pair of stations, E and F, at opposite sides of the base, and as far from each other as is consistent with making CDF and CDE well-conditioned triangles. Proceed as before to calculate the distance EF. This will probably be sufficiently long to serve as the side of a pair of triangles. If not, continue the process until a distance sufficiently long is obtained.

Verification Lines.—In order to provide a check on the work of the triangulation it is usual to measure in the field the distance of at least one line beside the base-line; a line so measured is called a verification line or base, and should be selected on ground suitable for linear measurement, and should occupy such a position with reference to the primary base-line that the whole of the angular measurements may be involved in its computation. The measurement is carried out in exactly the same way as that of the base-line, and, if possible, with equal accuracy.

Measuring the Angles.—The three angles of each triangle should be measured; it is, of course, possible to compute one angle in each triangle after measuring the other two, but by measuring the three angles a direct check on the measurements is obtained. In addition to measuring the angles themselves, the explementary angle should also be read; the latter observation should be made with the telescope in the reverse position with regard to the horizontal axis to that occupied when measuring the angle. In order to avoid any confusion, it is advisable always to measure angles in a clockwise direction. The verniers should be distinguished from one another by lettering or some other convenient means, and both verniers read for each observation. In sighting the signals, these should always be observed at their lowest point, in order to avoid errors due to want of verticality in the signals. As an example of the procedure to be followed, we may take the case when the instrument is occupying station *c* in the example on p. 194. After the theodolite has been centred and levelled up and the eye-piece of the telescope adjusted for parallax, the A vernier of the horizontal circle is set exactly to zero, and the reading of the B vernier noted; this should not vary throughout the whole series of observations. Assuming the vertical circle is on the left-hand side of the telescope, for the first observation the latter is noted as being face left. The body clamp is loosened and the instrument turned in azimuth until the signal at *b* is approximately in the centre of the field of view; the body clamp is tightened, and using the tangent screw attached to it, the bisection of the signal with the cross-wires is made. The signal should be accurately focussed before getting the bisection. The vernier clamp is now released and the instrument turned in azimuth until the signal at *g* is in the field of view; the vernier clamp is tightened, and the bisection of the cross-wires with the signal made with the aid of the tangent screw attached to the vernier clamp. The verniers are read, and the angles booked. As a check on the manipulation of the instrument during the foregoing operations, the vernier clamp is released and the instrument turned in azimuth and the signal at *b* again sighted, the bisection being obtained by means of the tangent screw attached to the vernier clamp, the A vernier should again read zero; if it does not, the whole of the operations must be repeated. The next step is the measurement of the corresponding explementary angle. The telescope is transited, and with the vernier A still clamped at zero, the body clamp is released and the instrument turned in azimuth and the signal at *g* bisected, the vernier clamp is released, and the instrument again turned in azimuth, and the signal at *b* bisected; the verniers now indicate the explementary angle, and this is read and booked. A check observation on to *g*, made by releasing the vernier clamp, turning in azimuth and obtaining the bisection with the aid of the tangent screw attached to the vernier clamp, should bring the A vernier back to zero. The angle and its explement should be totalled, and if the sum is 360°, within a reasonable limit (say 1 or 2 minutes), the measurement of the angles *gce* and subsequently *ecd* can be proceeded with. It is advisable to start the observations for each angle with the instrument always in the face left position or always in the face right position.

The angles may be booked as shown in the following example :—

EXAMPLE OF TRIANGULATION FIELD-BOOK.

Theodolite used was a 5-inch transit reading to 30″. When A vernier was at zero B vernier read 179° 58′ 30″.

Zero Station.	Instrument Station.	Forward Station.	ANGLE. Face-left.		EXPLEMENT. Face-right.		Mean.	Remarks.
			Vernier A.	Vernier B.	Vernier A.	Vernier B.		
f	*a*	*g*	35° 11′ 30″	215° 10′ 00″	324° 47′ 30″	144° 46′ 00″	35° 12′	..
g	*a*	*b*	67° 49′ 30″	247° 48′ 00″	292° 08′ 30″	112° 07′ 30″	67° 50′	..
a	*b*	*g*	52° 59′ 00″	232° 57′ 30″	307° 03′ 00″	127° 02′ 30″	52° 58′	..
g	*b*	*c*	36° 47′ 00″	216° 45′ 30″	323° 13′ 00″	143° 11′ 30″	36° 47′	..
b	*c*	*g*	57° 24′ 30″	237° 23′ 00″	302° 36′ 30″	122° 35′ 00″	57° 24′	..
g	*c*	*e*	85° 02′ 30″	265° 01′ 00″	274° 58′ 30″	94° 57′ 00″	85° 03′	..
e	*c*	*d*	57° 20′ 30″	237° 19′ 00″	302° 10′ 30″	122° 39′ 00″	57° 20′	..
c	*d*	*e*	69° 39′ 00″	249° 39′ 00″	290° 21′ 00″	110° 19′ 30″	69° 39′	..
d	*e*	*c*	53° 01′ 30″	223° 00′ 00″	306° 59′ 30″	126° 58′ 00″	53° 01′	..
c	*e*	*g*	38° 15′ 00″	218° 13′ 00″	321° 45′ 00″	141° 43′ 30″	38° 15′	..
g	*e*	*f*	42° 10′ 30″	222° 09′ 00″	317° 50′ 30″	137° 49′ 00″	42° 10′	..

In the above table the zero station is the one on the left and the forward station the one on the right looking from the station occupied by the instrument. Four values for each angle can be obtained from the above readings. One value is given direct in the fourth column, a second value is obtained by subtracting the zero reading of vernier B from the readings in the fifth column, a third value is obtained by subtracting the readings in the sixth column from 360°, and a fourth value by subtracting the zero reading of vernier B from the readings in the seventh column, and the residue so obtained from 360°. The mean of the four values is entered in the last column. Thus, taking the readings obtained for the angle *f a g* and its explement :—

1st value,	35° 11′ 30″, ...	35° 11′ 30″
2nd „	215° 10′ 00″ − 179° 58′ 30″, .	35° 11′ 30″
3rd „	360° − 324° 47′ 30″, . . .	35° 12′ 30″
4th „	360°−(144° 46′ 30″−179° 58′ 30″),	35° 12′ 30″
	Mean. . . .	35° 12′ 00″

The above method of observing the angles is in practice found to be very satisfactory; a much more usual method, however, when a number of angles have to be measured from one station, is to measure successive angles round the circle, only returning to the zero station after the set has been completed. The included angles between successive lines are obtained from the differences between successive readings. The explementary angles are measured after returning to the first station, by making a round of observations in the reverse direction—*i.e.*, the station last sighted for the first round becomes the zero for the second round. The telescope is transited between the two sets of observations. As an example, the procedure at station *c* (Fig. 80) may be taken. Station *b* is the zero station, the signals at *g*, *e*, and *d* are sighted successively, and the corresponding readings of the verniers taken. After returning to *b* for the check to zero, the telescope is transited, and the A vernier still being at zero, the signal at *d* is sighted, and then successively those at *e*, *g*, and *b* returning to *d* to make the zero check. To obtain the included angles and the explements corresponding to each, the difference between the successive vernier readings is taken in the two sets of observations.

Reiteration.—In this method of observing angles, one or more pairs of observations are made, the zero position being altered for each pair, the telescope also being transited between the taking of the observations. The number of reiterations depends upon the importance of the angles, and for mine-surveying purposes it is very rarely that more than two pairs are observed, and as a matter of actual practice usually only one pair is observed. The magnitude of the angle through which the zero position of the vernier should be moved depends upon the number of pairs observed; thus, if one pair only is observed, the respective zero positions for first and second observations are 0° and 90°. If two pairs of observations are taken, the respective positions for the zeros in the successive observations should be 0°, 60°, 60°, and 120°. This method of observation tends to the elimination of errors of centring and graduation.

The method of reiteration is very often applied in taking a round of observations, as described above, the zero position of the vernier when taking the observations for the explementary angles being 90°.

Repetition.—In measuring horizontal angles, when great accuracy is required, the errors of graduation may be diminished by the process known as *repeating*, an operation invented by Tobias Mayer, of Göttingen, in 1752.

The mode of procedure is as follows:—Determine the horizontal angle between the points A and B in the usual way, the vernier plate being clamped at zero. Let the angular distance between A and B be 30° 10′. Now, leaving the vernier plate clamped to the horizontal circle, release the body clamp, and turn the instrument back to A. Then tighten the body clamp, release the vernier plate, and again direct the telescope to B. In this way the reading will be repeated, beginning at 30° 10′ instead of 0° 0′. Suppose the result now is 60° 25′. Repeat again, starting this time from 60° 25′, and suppose that the third result is 90° 40′. Dividing this result by the number of readings, we obtain, as mean result, 30° 13′ 20″.

The operation may be repeated any number of times, care being always taken to direct the telescope towards A by turning the vertical axis, and towards B by turning the vernier plate. For each complete revolution of the vernier plate, 360° must be allowed. It is advisable to repeat the operation with the telescope inverted, and to take the mean of the two results obtained with the telescope n its two positions.

The following is an example of repetition:—

The horizontal angular distance between the two points determined in the usual way was 102° 45′. On repeating, the following results were obtained:—

No. of Repetitions.	Reading.	Mean.	Angle.
4	Ver. I. 51° 00′ 45″ Ver. II. 231° 00′ 45″	411° 00′ 45″	102° 45′ 11″
5	Ver. I. 153° 45′ 45″ Ver. II. 333° 45′ 45″	513° 45′ 45″	102° 45′ 09″
6	Ver. I. 256° 31′ 00″ Ver. II. 76° 31′ 00″	616° 31′ 00″	102° 45′ 10″

With the telescope inverted, the following results were obtained :—

No. of Repetitions.	Reading.	Mean.	Angle.
4	Ver. I. 51° 00′ 15″ Ver. II. 231° 00′ 15″	411° 00′ 15″	102° 45′ 04″
5	Ver. I. 153° 45′ 20″ Ver. II. 333° 45′ 30″	513° 45′ 25″	102° 45′ 05″
6	Ver. I. 256° 30′ 40″ Ver. II. 76° 30′ 30″	616° 30′ 35″	102° 45′ 06″

Mean = 102° 45′ 08″.

Checks on Angular Measurements.—Since the connected stations in a triangulation form a series of triangles, and the exterior sides of these again form a polygon embracing the whole system, it is evident that the observed angles should conform to the laws relating to the geometrical figures referred to. Thus, the sum of the angles at the corners of each triangle should total up to 180°; then, again, the sum of the included angles between all the adjacent sides of the polygon of n sides formed by the exterior lines of the triangulation should be equal to $n180° - 360°$. At interior stations where a complete round of angles is observed (hub stations), the sum of these angles should, of course, be equal to 360°. Summaries of the mean angles should be made and checked in the manner indicated. The discrepancies should be small, and if distributed evenly throughout the whole set of angles, should not amount to more than a few seconds per angle. It is advisable to distribute the errors so that the angles do conform in the manner stated to the geometrical figures in which they occur, but to alter each angle by a few seconds would unnecessarily increase the work of the subsequent computations, and would be quite inconsistent in most cases with the accuracy of the instrument used for measuring the angles. A satisfactory plan for a triangulation made with an instrument reading to 1′ or 30″ is to distribute the errors in such a way that the final angles are stated to not less than 20″. The more or less exact systems of distributing errors, employed for geodetic surveys, would be quite out of place for the relatively small triangulations that are under consideration, and for which a system of averaging the errors in the most convenient way to bring the summaries of the angles to the theoretical values is generally adopted. A diagram drawn to scale by setting out the observed angles, and on which their mean values are indicated greatly facilitates the distribution of the errors, as it does also the subsequent computation of the sides and the co-ordinates.

Computing the Sides of the Triangles.—For the solution of the triangles when the base and the three angles are given, the ordinary sine ratio is employed—

$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c},$$

when, if c represents the base,

$$a = \frac{c \sin A}{\sin C};$$

or, using logarithms,

$$\log a = \log c + \mathrm{L} \sin A - \mathrm{L} \sin C.$$

The sine of an angle A is equal to 1 ÷ cosec A. Instead, therefore, of subtracting L. sin C, L. cosec C may be added; the formula then is—

$$\log a = \log c + \mathrm{L.} \sin A + \mathrm{L.} \operatorname{cosec} C - 20.$$

In the survey of the triangles shown in Fig. 80, the base-line *af* was found on measuring to be 4009·5 links. The angles were as follows:—

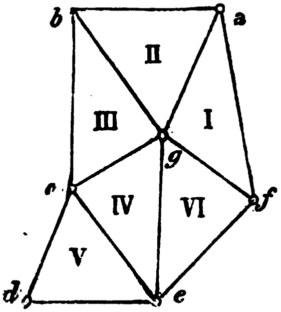

Fig. 80.

I.	*fag*	35° 12′	IV.	*cge*	56° 42′
	agf	104° 43′		*ecg*	85° 03′
	afg	40° 05′		*ceg*	38° 15′
II.	*abg*	52° 58′	V.	*dce*	57° 20′
	bag	67° 50′		*ced*	53° 01′
	agb	59° 12′		*cde*	69° 39′
III.	*cbg*	36° 47′	VI.	*egf*	53° 33′
	bgc	85° 49′		*efg*	84° 17′
	bcg	57° 24′		*feg*	42° 10′

The sides are calculated in the following manner :—

To find side $a\,g$ in Triangle I.

$$af : ag = \sin agf : \sin afg$$

$$\log ag = \log af + \text{L. } \sin afg - \text{L. } \sin agf.$$

$$\begin{array}{lcr}
\log 4009{\cdot}5 & = & 3{\cdot}6030902 \\
+\text{ L. sin } \ 40^\circ\, 05' & = & 9{\cdot}8088192 \\
-\text{ L. sin } \ 104^\circ\, 43' & = & 9{\cdot}9855135 \\
\hline
\log ag & = & 3{\cdot}4263959 \\
\hline
ag & = & 2669{\cdot}3 \text{ links.}
\end{array}$$

If instead of subtracting the sine of the angle opposite to the given side, its cosecant is added, the result will be as follows :—

$$\begin{array}{lcr}
\log 4009{\cdot}5 & = & 3{\cdot}6030902 \\
+\text{ L. sin } \ 40^\circ\, 05' & = & 9{\cdot}8088192 \\
+\text{ L. cosec } 104^\circ\, 43' & = & 10{\cdot}0144865 \\
\hline
\log ag & = & 3{\cdot}4263959
\end{array}$$

To find side $f\,g$ in Triangle I.

$$af : fg — \sin agf : \sin fag.$$

$$\begin{array}{lcr}
\log 4009{\cdot}5 & = & 3{\cdot}6030902 \\
+\text{ L. sin } \ 35^\circ\, 12' & = & 9{\cdot}7607483 \\
+\text{ L. cosec } 104^\circ\, 43' & = & 10{\cdot}0144865 \\
\hline
\log fg & = & 3{\cdot}3783250 \\
\hline
fg & = & 2389{\cdot}6
\end{array}$$

To find side $a\,b$ in Triangle II.

$$\begin{array}{lcr}
\log ag & = & 3{\cdot}4263959 \\
+\text{ L. sin } \ 59^\circ\, 12' & = & 9{\cdot}9339729 \\
+\text{ L. cosec } \ 52^\circ\, 58' & = & 10{\cdot}0078419 \\
\hline
\log ab & = & 3{\cdot}4582107 \\
\hline
ab & = & 2872{\cdot}2
\end{array}$$

To find side $b\,g$ in Triangle II.

$$\begin{array}{lcr}
\log ag & = & 3{\cdot}4263959 \\
+\text{ L. sin } \ 67^\circ\, 50' & = & 9{\cdot}9666533 \\
+\text{ L. cosec } \ 52^\circ\, 58' & = & 10{\cdot}0978419 \\
\hline
\log bg & = & 3{\cdot}4908911 \\
\hline
bg & = & 3006{\cdot}7
\end{array}$$

In the same way, the lengths of the other sides will be found to be as follows :—

Triangle III.

$$\log bc = \log bg + \text{L. sin } 85^\circ\, 49' + \text{L. cosec } 57^\circ\, 24' - 20$$

$$bc = 3666{\cdot}0 \text{ links.}$$

$$\log cg = \log bg + \text{L. sin } 36^\circ\, 47' + \text{L. cosec } 57^\circ\, 24' - 20$$

$$cg = 2201{\cdot}0 \text{ links.}$$

Triangle IV.

$$\log ce = \log cg + \text{L. sin } 56^\circ\, 42' + \text{L. cosec } 38^\circ\, 15' - 20$$

$$ce = 2971{\cdot}5 \text{ links.}$$

$$\log eg = \log cg + \text{L. sin } 85^\circ\, 03' + \text{L. cosec } 38^\circ\, 15' - 20$$

$$eg = 3541{\cdot}9 \text{ links.}$$

Triangle V.

$$\log cd = \log ce + \text{L. sin } 53^\circ\, 01' + \text{L. cosec } 69^\circ\, 39' - 20$$

$$cd = 2531{\cdot}7 \text{ links.}$$

$$\log de = \log ce + \text{L. sin } 57^\circ\, 20' + \text{L. cosec } 69^\circ\, 39' - 20$$

$$de = 2668{\cdot}0 \text{ links.}$$

Triangle VI.

$$\log ef = \log eg + \text{L. sin } 53^\circ\, 33' + \text{L. cosec } 84^\circ\, 17' - 20$$

$$ef = 2863{\cdot}3 \text{ links.}$$

$$\log fg = \log eg + \text{L. sin } 42^\circ\, 10' + \text{L. cosco } 84^\circ\, 17' - 20$$

$$\begin{array}{lcr}
\log eg & = & 3{\cdot}5492413 \\
\text{L. sin } 42^\circ\, 10' & = & 9{\cdot}8269098 \\
\text{L. cosec } 84^\circ\, 17' & = & 10{\cdot}0021653 \\
\hline
\log fg & = & 3{\cdot}3783164 \\
\hline
fg & = & 2389{\cdot}55 \text{ links,}
\end{array}$$

a result practically the same as that obtained in the solution of Triangle I.

Geodetic Surveys.—The triangulation-survey of a mine royalty is based on the same principles, operations, and methods as are adopted on the trigonometrical surveys of countries. In the latter surveys, the spheroidal form of the earth's surface has to be taken into account, and the amount of accuracy required is much greater than that required for any ordinary topographical survey. Thus, on the Ordnance Survey of the United Kingdom, the average length of the sides of the Primary Triangulation was 35 miles; the longest side was 111 miles. The angles were measured with four large theodolites, two 3 feet in diameter, one 2 feet, and one 18 inches. With the exception of the theodolite

2 feet in diameter, these instruments were constructed by Ramsden at the commencement of the trigonometrical operations in England in 1798. They are now exhibited in the South Kensington Museum, and are still in perfect condition.

In order to show how accurately the main triangulation was conducted, it may be mentioned that in 1826, a base-line was measured at Lough Foyle, in the north of Ireland, by means of General Colby's compensated bars, and in 1849 the old base-line on Salisbury Plain was remeasured with the same apparatus. The length of the Salisbury Plain base was 6·97 miles, and that of the Lough Foyle base 7·89 miles. The length of the latter base was calculated by a triangulation carried from the Salisbury Plain base, and the difference between the calculated and measured length of the Lough Foyle base was only 5 inches.

By means of secondary triangulation, the long sides of the principal triangulation were reduced to lengths of 5 miles. The angles were measured with a 12-inch theodolite. The stations selected were, as far as possible, permanent objects such as church towers.

The 5-mile sides of the secondary triangulation were reduced by means of the Parish triangulation to lengths of 1 mile, or less. In towns, the points were sometimes within as short a distance as 10 chains. The angles were measured with a 7-inch theodolite. Finally, the details were filled in by means of ordinary chain-surveying.

Determination of True Azimuths.—It is very often desirable to determine the true azimuths of the lines in a triangulation-survey, and this can be done by astronomical observations from one or two lines, and from these direct determinations the azimuth of any line in the triangulation can be obtained by computation, since all the angles between the lines are measured. There are a number of different methods of determining the true meridian or the angle which any given line makes with it, and the following are given as being sufficiently correct for the purposes of mine-surveying.

Method of Corresponding Altitudes.—This may be carried out with any good transit theodolite. The instrument is set up at a station on the line, the azimuth of which it is desired to measure. Vernier A of the theodolite is brought to zero, and the reading of vernier B noted.

The limb is then turned horizontally, and the telescope moved vertically until it is brought to bear upon a fixed star of the first or second magnitude several hours before its culmination.

As soon as the star passes the cross-wires of the telescope, the latter is clamped, and both the horizontal and vertical circles of the instrument are read. The telescope is then allowed to remain with its inclination unchanged, and after a time the star will not be visible through it. After its culmination, the star will, in the course of time, have the same altitude that it had at the first reading. The star is followed with the telescope, and at the instant it crosses the wires of the latter, the horizontal circle is read a second time.

Assuming that at the second reading the telescope had the same inclination that it had during the first reading, the direction of the meridian will be represented by half the sum of the two readings on the horizontal circle. The limb being turned horizontally until vernier A gives the calculated angle, the axis of the telescope will give the direction of the meridian. The method is based upon the fact that a star at equal altitudes above the horizon of a place is equally distant from the plane of its meridian.

It is evident that the accuracy of the result depends upon the perfection of the instrument employed. The best results are always obtained by observing the star at various altitudes before and after its culmination, and by reading the horizontal circle each time with the telescope clamped at the corresponding altitude. Both verniers should always be read, and the arithmetical mean of the readings taken if they are not identical. The direction of the meridian is thus obtained repeatedly, and if there is no error, the result will be the same with each inclination of the telescope. If the results differ slightly from one another, the mean must be taken; with larger differences, the observations must be repeated. As a check, the observations should be repeated on the following night with the telescope inverted. The result should not differ from that obtained on the previous night. If there is a slight difference, the mean of the results of the observations on the two nights will give the direction of the meridian.

As an example of this method of determining the meridian, some of the observations may be given which were made for fixing the meridian for the magnetic observatory belonging to the Clausthal mines. The determination was effected with an 8-inch theodolite. The instrument was set up on a stone foundation, and accurately levelled. The vernier I. was brought to zero, and the position of vernier II. noted. With the upper plate clamped in this position, the telescope was brought to bear on a signal on the top of the tower of Clausthal Church. The following observations were then made with the stars β and γ Virginis:—

Altitude of the Star.	Readings of the Horizontal Circle Calculated from the Position on the Two Verniers.		Angle formed by the Meridian and the Direction of Clausthal Church.
	Before the Culmination.	After the Culmination.	
(β Virginis)			
18° 20′	56° 15′ 37″	196° 22′ 05″	126° 18′ 51″
19° 40′	58° 15′ 12″	194° 22′ 45″	126° 18′ 58″
21° 00′	60° 18′ 52″	192° 18′ 50″	126° 18′ 51″
21° 40′	61° 21′ 42″	191° 15′ 20″	126° 18′ 31″
22° 20′	62° 25′ 57″	190° 11′ 45″	126° 18′ 51″
(γ Virginis)			
15° 20′	57° 40′ 32″	194° 57′ 25″	126° 18′ 58″
16° 40′	59° 40′ 02″	192° 57′ 55″	126° 18′ 59″
17° 20′	60° 41′ 47″	191° 56′ 15″	126° 19′ 01″
18° 00′	61° 43′ 57″	190° 53′ 55″	126° 18′ 56″
18° 40′	62° 47′ 07″	189° 50′ 05″	126° 18′ 36″

The zero of the horizontal circle represented the direction of Clausthal Church. The arithmetical mean of the results shows that the meridian formed an angle of 126° 18′ 51″ with the direction of Clausthal Church. Observations made the next night gave exactly the same results. The same number of observations were made on the two following nights with the telescope inverted. The mean of all the results obtained during the four nights gave 126° 18′ 49″. It must be noted that in these observations the stars employed were not first sighted and the angle of altitude then read. The vertical circle was clamped at a given division, and the star then brought on to the vertical wire of the telescope, and followed by means of the tangent screw of the upper plate until it also passed the horizontal wire.

If the theodolite is set up on a fixed point, and if the terrestrial object, the azimuth of which is determined, is also a secure point, a further marking-out of the meridian is not absolutely necessary. In the preceding case, however, it was thought advisable to mark out the meridian by means of a large square stone buried in the earth on a mountain in the vicinity. A hole drilled in this stone accurately in the meridian served for the reception of a signal staff.

This method may be carried out in the day-time by observations of the sun before and after noon. It is necessary to cut out the bulk of the sun's rays when observing with the telescope, and this is usually done by covering the eye-piece with a special mounting carrying a piece of suitable glass. The instrument is set up on one station of the line, the azimuth of which has to be determined and a signal pole placed at the other station. The vernier A is brought to zero and the position of vernier B noted. The horizontal angle which the sun makes with the triangulation line is measured, and also the vertical angle and the time of observation. Operations should be commenced at, say, 8 a.m., and observations taken every half-hour up to 11 a.m. At a little before the corresponding times after noon the vernier of the vertical circle is set to the vertical angle taken in the morning, and at the moment the sun touches the horizontal cross-wires the horizontal angle is read and the time again noted. As it is not feasible to obtain the intersection of the centre of the sun's disc with the cross-wires, the edge or *limb* of the disc is used. The position of the sun with relation to the cross-wires is shown in the case of two common forms of reticule in Figs. 81 and 82. S represents the position of the sun for the observation before noon and S^1 its position after noon. In order to eliminate collimation errors and the error due to the cross-wires not being exactly at right angles in one case, and the error due to want of symmetry in the other, a second series of observations made with the telescope, inverted with regard to the horizontal axis, should be made, preferably on a succeeding day, or if climatic conditions prevent this, they should be made as soon as possible after the first series. S^2 and S^3 represent the positions of the sun in relation to the cross-wires for the second set of observations, respectively before and after noon. The bookings should be entered in exactly the same way as those shown on p. 199, except for the addition of the time of observation.

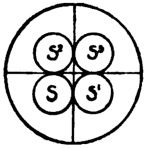

Fig. 81.

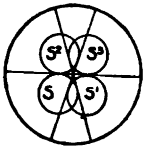

Fig. 82.

Unless the observations are made at the time of the solstices

(June 21 and December 22), a correction has to be applied to the determination of the meridian by the foregoing method. This is necessary on account of the change in the sun's declination between the times of the corresponding observations before and after noon. The data for making the necessary correction are the latitude of the place of observation, the rate of change of declination of the sun and the interval of time between the corresponding observations. The latitude may be ascertained from a map or from observation, the change in declination is taken from the *Nautical Almanack* or *Whittaker's Almanack*. The correction is made as follows :—Let A be the true angle that the sun makes with the meridian at the time of the observation before noon, A′ be the true angle that the sun makes with the meridian at the corresponding time of observation after noon. Let D be the variation in declination between the observations, and let t be half the difference in time expressed as an angle, then $A - A' = \dfrac{D}{\cos L . \sin t}$.

In the northern hemisphere, when the sun is north of the equator and the declination is increasing, or when it is south of the equator and the declination is decreasing, the value of D is positive. When the sun is south and the declination increasing, or when it is north and the declination is decreasing the value of D is negative.

If B be the reading of the horizontal circle at the observation before noon, and C the reading of the corresponding observation after noon, the corrected angle formed by the triangulation line and the meridian is equal to

$$\tfrac{1}{2}\{B + C - (A - A')\}.$$

The following example will serve to illustrate the application of the correction :—

On July 6th, 1915, from a point A in latitude North 54° 58′ the following observations were taken of the sun for the purpose of determining the azimuth of a line A B. The vernier of the horizontal circle of the theodolite was reading zero when the telescope was directed to B :—

Morning Observations.			Afternoon Observations.	
Time.	Vertical Angle.	Horizontal Angle.	Time.	Horizontal Angle.
8.27 a.m.	40° 28′ 00″	138° 16′ 30″	3.31 p.m.	279° 28′ 30″

On this date the sun's declination was decreasing at the rate of 14·23″ per hour, the sun being to the north of the equator.

The formula to obtain the correction is

$$\mathrm{A} - \mathrm{A}' = \frac{\mathrm{D}}{\cos \mathrm{L}.\sin t},$$

the value of D being negative in this case.

Interval of time between observations is 7·07 hours.

$$\mathrm{D} = 14{\cdot}23 \times 7{\cdot}07 = -\,100{\cdot}5''$$

$$t = \frac{7{\cdot}07}{2} \times \frac{360}{24} = 52^\circ\,48'\,00''$$

$$\mathrm{A} - \mathrm{A}' = \frac{-100{\cdot}5}{\cos 54^\circ\,58'\,.\,\sin 53^\circ\,01'\,30'} = -\,3'\,39'',\ \text{say},\ -\,3'\,40''.$$

Angle formed by sun with line A B

$$= \tfrac{1}{2}\{138^\circ 16'\,30'' + 279^\circ\,28'\,30'' - (-\,3'\,40'')\} = 208^\circ\,54'\,20''.$$

In this latitude, the sun being to the south of the point of observation, the angle measured from A B to the true North is 208° 54′ 20″ − 180° = 28° 54′ 20″. The azimuth of the line A B = 331° 05′ 40″.

Determination of Meridian by Shadows.—The method of equal altitudes may also be applied to rough determination of the true meridian by measuring the lengths of shadows cast by the sun. The lengths of the shadows of a vertical object, cast by the sun on a horizontal plane, are equal for equal altitudes of the sun.

A staff is planted vertically in the ground, and the ends of its shadows are joined when they are of equal length. On joining these points to the projection of the axis of the staff, an angle is obtained, the bisectrix of which is the true meridian. The observation may be made more accurately by describing a number of concentric circles (Fig. 83) with the foot of the staff as centre, and marking the points, *a*, *b*, *c*, *d*, *d′*, *c′*, *b′*, *a′*, where each of them is touched by the shadow. The arcs thus obtained are bisected, and the points of bisection are joined to the centre of the circle. The line *m m* thus obtained is the meridian. This is the oldest method known; it was used by the early Christians for determining the east for their churches.

The method is considerably improved by placing a thin metal plate provided with a small aperture, at the top of the staff. The latter is inclined so that the aperture is perpendicularly above the centre of the concentric circles. In the shadow of the metal plate, a bright spot appears, the centre of which can be found with considerable accuracy. This method has been used on a large scale by placing perforated metal plates in the roofs of high buildings, a notable example being in the dome of the cathedral at Florence (1467, A.D.).

The shadow method may be applied on a small scale by employing a vertical pin placed in the centre of a number of concentric circles on a drawing-board. A more convenient apparatus may be made of a brass rod about 7 inches in length, provided at its lower end with a screw and at the top with a very thin plate of brass about 2 inches long and 1½ inches broad, so arranged that it forms with the pin an angle of about 120°. In the middle of the plate a fine hole is drilled. The pin being screwed into a board, half an inch square, near the edge, a portable instrument, Fig. 84, termed a *gnomon*, is formed. This can be placed on a table or drawing-board in the open air, and used in the manner described.

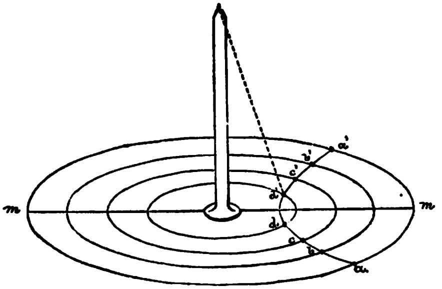

Fig. 83.

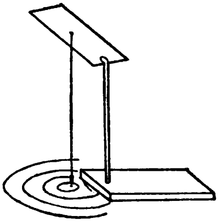

Fig. 84.

Determination of the Meridian by Means of the Pole-Star.—Of the bright stars of the northern heavens, the nearest to the pole is the first star in the tail of the Little Bear, or the Pole-star (α Ursæ Minoris). It is a star of the second magnitude, and may easily be found by imagining a straight line to be drawn through the stars β and α of the Great Bear, and continued for about five times the distance from β to α, counting from α. These two stars are known as the *pointers*.

The meridian may be determined by observing the pole-star either when it is in the meridian, or when it is at its extreme elongation. The pole-star is not situated exactly at the north pole of the heavens, but is now about 1° 12′ from it. Twice in each sidereal day (23 hours 56 minutes) it is in the meridian.

A very simple method of determining the meridian of a place consists in sighting the pole-star, marked A in Fig. 85, when it appears in the same vertical line with the star Alioth in the Great Bear (ε Ursæ Majoris). This may be done by watching for the moment, when a suspended plumb-line will cover both stars. They will then be approximately in the meridian. The pole-star is exactly in the meridian about 29 minutes after it has been in the same vertical plane as Alioth. In the southern hemisphere a similar process may be applied to the stars α′ Crucis and β Hydri.

The meridian may also be determined by observing the pole-star at its extreme elongation—that is, when it is at its greatest apparent angular distance east or west of the pole. At this instant, the horizontal projection of the apparent movement of the star alters its direction, and the motion of the star appears to cease for a short time. The greatest and least horizontal angles made by the pole-star with any given line when the star is at the greatest distances east and west of the pole, are observed and the mean of the angles taken. This will be the angle made by the given line with the meridian. This method is rarely practicable with an ordinary theodolite, as one of the observations must generally be made by daylight.*

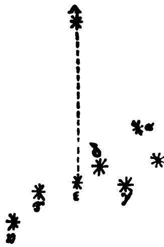

Fig. 85.

The Solar Attachment is a contrivance that is fastened to the telescope axis of American transit instruments for the purpose of determining the true meridian. The principle was enunciated by W. A. Burt, of Michigan, and applied by him to the compass in 1836. It has since come into general use in the surveys of the United States public lands, the principal lines of which are set-out with reference to the true meridian.†

The Burt solar compass consists mainly of three arcs of circles, by which can be set off the latitude of a place, the declination of the sun, and the hour of the day. Through the centre of the hour arc passes a hollow socket, containing the spindle of the declination arc. This is termed the polar axis. When this axis is parallel to the axis of the earth, the vertical plane of the terrestrial line of sight, as defined by the slits in the vertical sights of the compass, coincides with the meridian.

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* A method of conducting daylight observations is described by W. O. Owens, *Eng. and Min. J.*, vol. lxxv., 1903, p. 84.

† A detailed history of solar surveying instruments has been written by J. B. Davis, *Trans. Amer. Inst. M.E.*, vol. xxx., 1901, p. 803

Fig. 86 represents the solar apparatus placed upon the cross-bar of the transit-theodolite. The form represented was patented by Messrs. W. & L. E. Gurley, of Troy. The following is the manufacturers' description of this attachment:—A small circular disc, 1½ inches in diameter, with a short round pivot projecting above its upper surface, is first firmly screwed to the telescope axis. Upon this pivot rests the enlarged base of the polar axis, which is also firmly connected with the disc by four capstan head screws passing from the under side of the disc into the enlarged base. These screws serve to adjust the polar axis.

The hour circle surrounding the base of the polar axis is easily movable about it, and can be fastened at any point desired by two flat-headed screws above. It is divided to 5 minutes of time. It is figured from I. to XII., and is read by a small index fixed to the declination circle moving with it. A hollow socket, fitting closely to the polar axis, moves upon it, and may be clamped at any point desired by a milled-head screw on top. By its two expanded arms below, this furnishes a firm support for the declination arc, which is securely fastened to it by two large screws.

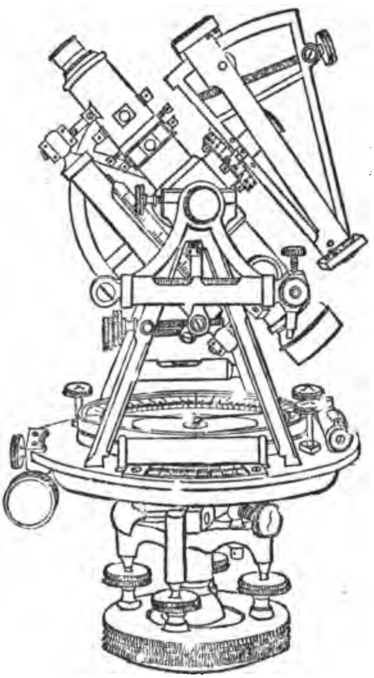

Fig. 86.

The declination arc is about 5 inches in radius. It is divided to quarter-degrees, and reads by its vernier to single minutes of arc, the divisions of both vernier and limb being in the same plane. At each end of the declination arm is a rectangular block of brass, in which is set a small convex lens, having its focus on the surface of a small silver plate fastened by screws to the inside of the opposite block. On the surface of the plate, two sets of lines are marked intersecting each other at right angles. The two sets are termed the hour lines and the equatorial lines, as having reference respectively to the hour of the day and the position of the sun in relation to the equator. The declination arm is also provided with a clamp and tangent movement.

The latitude is set off by means of a large vertical limb, below the telescope, having a radius of 2½ inches. The arc is divided to 30 minutes, and is figured from the centre each way in two rows, from 0° to 80°, and from 90° to 10°, the former series being intended for reading vertical angles, the latter for setting off the latitude. It is read by its vernier to single minutes. It has a clamp screw inserted near its centre, by which it can be clamped to the telescope axis in any desired position. The vernier of the vertical limb is made movable by the tangent screw, attached so that its zero is readily made to coincide with that of the limb when the arc is clamped to the axis in adjusting the limb to the level of the telescope.

A spirit-level on the under side of the telescope, provided with a scale, is indispensable in the use of the solar attachment.

When the telescope is made horizontal by its spirit-level, the hour-circle will be in the plane of the horizon, the polar axis will point to the zenith, and the zeros of the vertical arc and its vernier will coincide. In this position of the instrument, if the arm of the declination arc is placed at zero, and one lens directed to the sun, its image will be seen between the lines on the silver plate of the opposite block, and will indicate its position in the heavens, on an instrument placed at the North Pole of the earth at the time of the equinoxes, or when the equator is in the plane of the horizon. If the telescope is inclined, as shown in Fig. 86, the polar axis will descend from the direction of the zenith. The angle through which it moves, being laid off on the vertical arc, and shown by its vernier to be (say) 40°, will be the co-latitude of the place where the instrument is supposed to be used. The latitude itself is found by subtracting 40° from 90°, making it 50°. Now, if the declination arm remains at zero, and the lens is again directed to the sun, its image will appear on the opposite plate as before, the instrument being used at the time of the equinoxes at a latitude of 50°. When, however, the sun passes above or below the celestial equator, its declination or angular distance from it, as given in the *Nautical Almanack*, can be allowed for and set off upon the arc, and the image brought into position as before.

In order to do this, it is necessary that the latitude and declination be correctly set off upon their respective arcs, and that the instrument be moved in azimuth until the polar axis points to the pole of the heavens, or, in other words, is placed in the plane of the meridian. Thus the position of the sun's image will not only indicate the latitude of the place, the declination of the sun for the given hour, and the apparent time, but also determine the meridian line passing through the place where the observation is made.

The latitude of a place—that is, its distance north or south of the equator, measured on a meridian—may be found by means of the solar attachment in the following manner :—First carefully level the instrument by means of the spirit-level of the telescope. Next clamp the vertical arc, and, by means of the tangent screw, make its zero and that of the vernier exactly coincide. Then, having the declination of the sun for 12 o'clock of the given day as affected by refraction carefully set out upon the declination arc, note also the equation of time. The sun is sometimes faster and sometimes slower than a clock adjusted to mean time, the difference being termed the equation of time. Fifteen or twenty minutes before noon, the telescope is directed to the north, and the object end lowered until, by moving the instrument on its spindle and the declination arc from side to side, the sun's image is brought nearly into position between the equatorial lines. Then bring the declination arc directly in line with the telescope, clamp the axis firmly, and with the tangent screw bring the image precisely between the lines, and keep it there with the tangent screw, raising it as long as it runs below the equatorial line—that is, as long as the sun continues to rise in the heavens.

When the sun reaches the meridian, the image will remain stationary for an instant. The instant is, of course, apparent noon when the index of the hour-arc should indicate XII. The latitude is determined by reading the vertical arc.

The angle through which the polar axis has moved, being measured from the zenith and not from the horizon, the angle read on the vertical limb is the complement of the latitude. The latitude may, however, be read direct from the inner row of figures on the arc, beginning with 90 at the centre and running to 10 on either side.

A very important addition to the solar attachment, patented by Messrs. W. & L. E. Gurley, is shown in fig. 86. It is an arrangement for recovering the latitude of a solar transit-theodolite without referring to the vertical arc, and generally for setting the telescope at any desired angle in setting-out inclines. It consists of a spirit-level, connected by a short conical socket with the end of the telescope axis, to which it is clamped by a milled-head screw, and made adjustable by a screw and spring on opposite sides of the enlarged end of the level-tube. When the milled-head screw at the telescope axis is released, the level turns vertically upon the axis, and can thus be set at any angle with the telescope.

The latitude being set off upon the vertical arc, as usual, the level is clamped, and centred. The telescope may then be released and used in running lines, until it is desired to recover the latitude again. This is accurately done with the spirit-level alone without referring to the vertical arc.

The declination of the sun given in the *Nautical Almanack* from year to year is calculated for apparent noon at Greenwich. To determine it for any other hour at any other place, reference must be made not only to the difference of time arising from the longitude, but also to the change of declination from day to day. Thus, supposing that the observations are being made at a place eight hours west of Greenwich, the declination given in the almanack for Greenwich noon of any day, will correspond to the declination at the place in question at 4 o'clock a.m., of the same date. To this must be added algebraically the hourly change in the declination, also given in the almanack. A table may thus be prepared giving the declination for each hour of the day.

Determination of the Meridian by means of a Map.—For an approximative determination of the meridian, a large-scale map may be employed. The direction of the meridian is shown by joining the degrees of longitude marked at the top and bottom of the map. The angle formed by the meridian and some line easy to determine on the ground, is measured on the map. With the aid of this line, the angle is marked off on the ground. The approximation thus obtained is about 15 minutes.

Interior Detail of the Triangulation.—For surveys of very extensive royalties it may be advisable to carry out a minor triangulation in order accurately to fix the positions of points sufficiently close together, so that the detail may be filled in with an accuracy consistent with that of the triangulation, but this is not usually necessary if the main triangulation has been carefully laid out.

When the detail is to be filled in by chain-surveying, it is advisable to put in pegs on the triangulation lines at all points where cross lines from one main line to another may be required, ranging for this purpose being performed with the theodolite. The main lines are then chained in order to fix the positions of the pegs. As the total distances of the main lines have already been accurately determined, the errors in chaining are known, and the positions of the pegs can be accurately fixed by making allowances proportional to the distances of each; due allowance should be made for particularly difficult ground. The field-book for the detail is entered in all respects similarly to the method given in the chapter on chain-surveying.

Traversing forms a very convenient method of filling in details, especially in hilly country, as the vertical angles can also be measured, and the necessary allowances for distances measured on the slope accurately made. Offsets are taken from the traverse lines in exactly the same way as in chain-surveying. It is advisable to run the traverses between the main triangulation stations, using the main line as the standards for direction, the traverses can then be accurately checked. The azimuths of the separate traverses should all be determined from a common meridian, otherwise confusion may arise in plotting. The theodolite should be used for the more important detail, such as the boundary, principal roads and buildings; the interior fences, etc., being filled in by compass traverses made with the dial or prismatic compass.

As already mentioned, in this country much of the less important detail can be obtained from the 1/2500 ordnance maps, which are sufficiently detailed for this purpose. Measurements from well-defined features in the field are made from the triangulation stations, so that these can be plotted accurately on the maps; the measurements of the details on the latter can then be made with reference to the triangulation lines and transferred to any convenient scale to which the main triangulation is plotted. This method is particularly useful in connection with colliery plans, which at the present time are required to be drawn on a scale of not less than two chains to an inch.

Surveying by the plane table (see Chapter XIV.) is also particularly well adapted for filling in details of triangulation-surveys.

CHAPTER XIII

Plotting the Survey.

Scales.—Plotting a survey consists in representing on paper, to a smaller scale, the lines and angles determined on the ground. The operation of drawing lines, the length of which shall be some fraction of that of the lines measured on the ground, is called *drawing to scale.*

A scale may be defined as an artificial means of representing any given dimensions. Thus, a fathom may be represented by a straight line 1 inch long; then 2 fathoms would be represented by a line of 2 inches, 3½ fathoms by 3½ inches, and so on. Scales may be divided into two classes—viz., *simply divided* scales and *diagonal* scales.

Simply divided scales consist of any extent of equal divisions, numbered 1, 2, 3, etc., beginning at the second division on the left hand. The first of these primary divisions is sub-divided into 10 equal parts, and from these sub-divisions the scale is named. Thus it is a scale of 30, when 30 of these secondary divisions are equal to 1 inch. If the primary divisions are taken as units, the secondary divisions will represent tenths.

As an illustration of the method of constructing scales, let it be required to construct a scale of 3 chains to the inch, to exhibit 18 chains. Draw a line 6 inches long, and divide it into 18 equal parts. These are the primary divisions, each of which represents one chain. Divide the first primary division into 10 equal parts; each of these secondary divisions will represent 10 links. Next draw a thicker line at a short distance below the first line, and draw vertical lines between them to indicate the divisions of the first lines. Place the zero at the line between the first and second primary divisions, and then, from left to right, place in succession the numbers 1, 2, 3, etc., at each primary division. Number the secondary divisions from the zero from right to left, 0·1, 0·2, 0·3, etc. With this system of numbering, lengths are taken from the scale with greater facility. Thus, to take off 3 chains

25 links from the scale described, one point of the dividers must be placed at the figure 3 on the scale, and the other point extended back to a place midway between the second and third secondary divisions.

In cases where fathoms and feet are required to be shown, the first primary division is divided into 6 divisions representing feet. If the scale is to show feet and inches, the first primary division must be divided into 12 equal divisions, representing inches.

A scale constructed in this way should be drawn upon every mine plan. Paper, when exposed to atmospheric influences, is found to expand or contract to a considerable extent. This is especially the case with new paper, or newly-mounted paper. The serious errors apt to arise from this cause are, to a large extent, obviated by making a scale on the paper as an accurate standard of measurement. This will expand and contract with the paper, and thus afford a valuable indication of the state of the paper.

The scales usually employed for the plans of metalliferous mines are 4 or 8 fathoms to the inch, sometimes 5 or 10 fathoms. For colliery plans, scales of 2 or 3 chains to the inch, or of 25·34 inches to the mile, are the most usual.

In order to assist in giving a clearer idea of the relative proportions of the scales used, it is desirable that they should be expressed fractionally—that is to say, that they should be so named as to indicate the ratio the line drawn on the paper bears to the line measured on the ground. Thus, a scale of 2 fathoms to the inch is a scale of $\frac{1}{144}$, or, as it may also be written, 1 : 144, since 1 inch represents 2 fathoms, or 144 inches of real length. A scale of this kind is called a *natural* scale.

In the construction of the maps of the Ordnance Survey of Great Britain, the following scales are used :—

Towns, . . .	1 : 500, or	126·72	inches to the mile.
Parishes, . .	1 : 2500, or	25·34	,, ,,
Counties, . .	1 : 10560, or	6	,, ,,
The Kingdom, .	1 : 63360, or	1	inch ,,

In the scale adopted for the parish maps, largely used for colliery plans, 1 square inch represents very nearly an acre.

Diagonal Scales.—A diagonal scale of equal parts is constructed in the following manner :—Draw eleven straight lines parallel to each other and $\frac{1}{10}$ inch apart. Divide the top line into equal parts, these primary divisions being of any required length.

Through the points marking these primary divisions, draw perpendiculars cutting all the parallels. Number the primary divisions from the left, 10, 0, 10, 20, 30, etc., as in the case of the simply divided scale. Then sub-divide the top and bottom lines of the first primary division into 10 equal parts. Number the alternate divisions, 2, 4, 6, 8, from right to left along the bottom line, and number the alternate parallel lines, 2, 4, 6, 8, from the bottom upwards. Then draw lines, as in Fig. 87, from the zero of the bottom line to the first division of the top line, from the first of the bottom to the second of the top, and so on until the scale is complete.

The diagonal lines are all parallel. Consequently the distance between any two successive lines, measured up any of the eleven parallel lines which they intersect, is the same as the distance measured upon the highest and lowest of those lines. The distance between the prependicular which passes through the

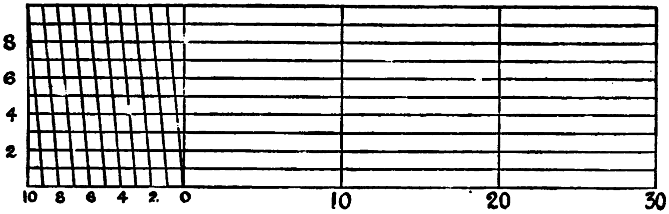

Fig. 87.

zero point, and the diagonal at the same point, is 0 on the top line, and equal to one sub-division on the bottom line. It is, therefore, equal (*Euclid*, vi. 4) to one-tenth of a sub-division on the second line, two-tenths of a sub-division on the third, and so on. In this way, each of the diagonal lines, as it reaches each successive parallel, separates farther from the perpendicular through the zero point by one-tenth of the extent of a sub-division, or one-hundredth of the extent of a primary division. Thus, by means of a diagonal scale a distance can be taken off to two places of decimals.

The general rule for taking off any distance stated in three figures from a diagonal scale is as follows:—On the parallel line indicated by the third figure, measure from the diagonal indicated by the second to the vertical indicated by the first.

Plotting Scales.—The most convenient scales of equal parts for plotting are those of ivory or boxwood; scales made of the latter material, if it has been well seasoned, are remarkable for their constancy, being in this respect superior to ivory scales. Scales having edges divided on celluloid are also very extensively used. Plotting scales have a feather edge, along which they are divided, the divisions usually being made decimally. The two edges of the scale are generally graduated differently, thus a scale of 1/2500 may be divided to read chains and links on one side and either yards or feet on the other. When the two edges are differently graduated, the distinction should be very marked, otherwise confusion may arise in plotting from using the wrong side of the scale inadvertently. Scales divided into an even number of divisions per inch can be used in several different ways, thus a scale of 20 divisions to the inch may be used for 20 feet or 20 units of any measurement per inch, and also as a scale of 2 chains to the inch, each small division then representing 10 links and 10 of the small divisions representing a chain.

The most convenient way of using plotting scales is to lay them directly along a line either for setting off a given distance or measuring the length of a given line; the use of dividers is not only unnecessary, but inadvisable, as the marks made by the points very soon ruin the graduations. When it is necessary to set a pair of compasses to a given distance, the latter should be marked off on a piece of paper and the compass set from the paper.

Each plotting scale, which is usually either 10 or 12 inches long, should be provided with a shorter scale for the purpose of plotting offsets. Offset scales are usually about 2 inches long, with the zeros of the graduations exactly at the end of the scale. The ends are finished so that they are accurately at right angles to the graduated edges, and the scale thus forms a set-square with which offsets can be marked off without drawing perpendiculars from the points at which they are taken on the chain line.

Plotting of Chain-Surveys.—Chain-surveys are plotted by constructing triangles having sides corresponding to the distances of the chain lines. A plotting should be made in the first instance to a small scale, so that the size of the paper for the finished plan can be accurately gauged, as well as the best position for laying down the first line. In extensive surveys the lengths of the main lines are usually such that beam compasses are required for striking the arcs for the construction of the triangles. They consist of a set comprising a needle point, pencil point, and a pen, the latter being very rarely required for surveying purposes; they are constructed so that they can be clamped on to a wooden or light metal lath of any convenient length. In setting a beam compass to mark off a distance, the latter is marked along a line drawn on a piece of paper by means of the plotting scale. The needle point of the compasses is clamped at one end of the lath, and the pencil point is set at the approximate distance and also clamped. The needle point is set into the paper at one end of the line, and the position of the pencil point set accurately to the other mark by means of an adjusting screw provided for the purpose.

The following is the usual procedure in plotting—taking the case of the example given in the chapter on chain-surveying, and working from the diagram of lines and the field-book. Line 1 is drawn on the paper, using a good quality pencil of HH grade, and sharpened to a chisel point. The distance is marked off with the scale, using a pricker to mark the end stations. The distance of line 2 is then obtained on the compasses, and an arc struck on the side of line 1, as indicated by the diagram. The compasses are then set to the distance corresponding to line 3, and an arc intersecting the first one is drawn. Lines drawn to the intersection from the ends of line 1 represent lines 2 and 3. If the lines are very long, it is advisable to draw them in very lightly at first, and to check the distances to the intersection with the scale, as it is very difficult to strike accurately an arc with a long radius by means of the beam compasses, especially on new mounted paper which does not lie perfectly flat. The distances having been checked, and the intersection point corrected if necessary, the intersection of line 4 with line 1 is obtained from the notes and marked off with the pricker from the plotting scale. Line 4 is now drawn in lightly, and its distance measured off with the scale; if the plotted distance tallies with the measured distance as recorded in the notes, then lines 1, 2, 3, and 4 can be accepted as correctly chained and plotted, and the lines can be drawn in distinctly and numbered. If the distances of the lines are greater than the length of the plotting scale, even distances of, say, 10 chains, 20 chains, etc., depending on the scale of the plan, are accurately marked off along the line in the direction of the chaining. These marks are used in the subsequent plotting of the offsets, and also enable any subsequent contraction or expansion of the paper to be noted and allowed for. Lines 5 and 6 are next plotted and checked in the same way as before, line 7 forming the check line for this triangle. Lines 8, 12, and 13 are then plotted, then 9, 10, and 11. Lines 14, 15, and 16 complete the main lines. The plotting of the main lines when once commenced should be completed with as little delay as possible, so as to avoid changes due to contraction or expansion of the paper during the plotting, otherwise subsequent changes will not affect the plan uniformly and accurate allowances will be impossible. The remainder of the lines are plotted by finding from the notes the intersections with the lines they connect and pricking them off from the scale. The plotted distance of each line should be compared with its measured distance before proceeding with the plotting of the next line. Notes should be made of any discrepancies that cannot be traced to errors in plotting, so that the measurements can be checked in the field. The stations should all be marked with the pricker and a small circle drawn round each, the station lines being drawn up to the circumferences only, thus leaving the stations quite clearly defined.

Offsets are put in by means of the offset scale corresponding to the plotting scale. The latter is set along the station line with its zero on the starting point of the line, and held in position by flat-shaped weights. The offset scale is placed with its end against the graduated edge of the plotting scale, and slid along until one of its graduated edges is at the reading of the plotting scale corresponding to a distance on the chain line where an offset has been measured. The length of the offset is then set off by simply marking the distance with a finely-pointed pencil. A pricker should not be used for this purpose, as the holes it would make would interfere with the subsequent inking in of the detail. All the offsets on the one side of the line within the length of the scale are plotted before proceeding to plot those which may have been taken on the other side, these being put in after the scale has been turned round. The offsets should then be joined up before moving the scale along the line, otherwise if too many unconnected points are plotted there is a liability to connect them up incorrectly.

Plotting of Traverse Surveys.—Traverses may be plotted directly by setting out the directions and distances of the successive lines, or their co-ordinates with reference to a pair of axes at right angles to one another may be determined, and the stations plotted from the co-ordinates.

Plotting with the Protractor.—In this method a circular protractor for laying out the directions and a parallel ruler for transferring them to any desired point are required, in addition to the usual scales, etc. Various forms of protractor are used, some being very elaborate instruments provided with verniers reading to minutes. A simple circular protractor, engine divided to half-degrees and made of brass, celluloid, or cardboard, is, however, amply efficient. Where an accuracy of plotting greater than can be obtained by such a protractor is required, it can be more readily attained by the method of co-ordinates. Semi-circular protractors should not be employed for plotting. The diameter of the graduated edge of the protractor should be not less than 6 inches, and should be divided to half-degrees; its centre must be accurately marked, and it may with advantage be doubly figured in a clockwise direction, the figuring starting from opposite ends of a diameter, so that the zero of the outer set of figures corresponds to 180° in the inner set of figures. Cardboard protractors are usually printed from an engine divided block, and the diameter of the graduated circle is usually 12 inches.

The parallel ruler should be of the rolling form, and not less than 18 inches in length. The accuracy of the ruler depends mainly on the rollers being of exactly the same diameter and on the distance apart of the rollers, the latter should not be too small or set too closely together. The ruler may be made of ebony, or preferably, brass or gun-metal. The surface of the drawing-board on which the paper is laid when plotting must be true, otherwise the ruler will not roll truly.

The procedure when using a metal or celluloid protractor is as follows:—The starting point of the traverse having been fixed on the paper either from a trial plotting to a small scale or by other means, a meridian line is drawn on the paper near this, and a line at right angles to the meridian is drawn to represent the east and west lines, the intersection of the two being the point at which the centre of the protractor is set. The divided edge of the latter is turned until the zero of the outer set of figures coincides with the north line, the east, south, and west lines should then read 90°, 180°, and 270° respectively. The azimuth of each line of the traverse is then pricked off, first from the outer figuring, readings of less than 30′ being obtained by estimation. Each prick mark is distinguished by writing against it the number of the line to which it corresponds or the corresponding azimuth, the latter being generally preferred. The direction of the line is also indicated by drawing an arrow-head. Corresponding prick marks are then made from the inner figuring, again distinguishing the marks as before, but leaving out the arrow-heads. The protractor is removed from the paper, and the setting out of the direction can be checked by laying a straight edge in contact with opposite corresponding marks, the straight edge should in each case be also exactly in contact with the point previously occupied by the centre of the protractor.

The edge of the parallel ruler is then brought into contact with the marks corresponding to the direction of the first line, and the ruler rolled until the edge is in contact with the starting point of the traverse. A line is then drawn on the paper in the direction indicated by the arrow-head, and slightly longer than the distance of the line; the distance from the starting point is then pricked off from the scale. The end of the first line forms the starting point for the second line; this can be plotted forthwith, and all the successive lines plotted in the same manner. The number should be written against each line as it is plotted.

If the edge of the plotting scale is quite true, the neatness and accuracy of the plotting can be increased by the following modified procedure:—The parallel ruler having been set to the direction and rolled back to the starting point of the line, the pricker is put lightly into the paper in contact with the edge of the ruler, and at a distance of slightly less than the full scale length, and held there; the ruler is rolled out of the way, and the scale is placed so that its zero is at the starting point and its edge also in contact with the pricker. The latter is then used to mark off the exact distance of the line, and a pencil line is drawn nearly up to the prick-mark, which is ringed after the scale has been removed.

The use of a cardboard protractor enables the survey to be plotted much more expeditiously than is possible with a protractor of metal or celluloid, and with an accuracy at least equal. A circle is cut out inside the graduated ring, the diameter of the cut-out portion being rather less than the distances between the rollers of the ruler that is to be employed for the plotting. A line is drawn through the zero and 180° mark on the protractor to both the inside and outside edges, to form the north and south lines for setting the protractor, which is then laid on the paper with this line coinciding with a meridian line drawn near the starting point of the traverse as before, but with the starting point inside the cut-out portion. The most convenient figuring for the graduation is that suggested for the previous form—viz., two sets of figures running clockwise from the north and south lines respectively. The parallel ruler is laid across the divided circle, care being taken to see that both rollers are on the cardboard, the edge is brought to read the azimuth on both sets of figures, the outer set giving the proper direction for the line. As this divided circle is large enough to be divided into quarter-degrees direct, it is possible to read by estimation to about three minutes on either side, so that the azimuths can be set off with considerable accuracy. The ruler is then rolled until its edge is exactly over the starting point of the traverse, and a pencil line is drawn in the direction of the line; the ruler is rolled out of the way, and the distance pricked off from the scale. The station so obtained is ringed, the line numbered, and the plotting of the second and all succeeding lines carried out in the same way. The protractor is moved along the meridian line in order to bring fresh portions of the paper within the cut-out circle as the plotting proceeds. A modification of the method, similar to that previously described may with still greater advantage be applied to plotting with the cardboard protractor. The ruler having been set to the azimuth is rolled until it is exactly over the starting point, the setting being facilitated by holding the pricker lightly in the paper at the point and keeping the needle as vertical as possible. The pricker is taken from the paper and put into the cardboard in contact with the edge of the ruler, and slightly less than a scale length away from the starting point, and held in position; the ruler is rolled out of the way and the scale laid with its zero at the starting point and its edge in contact with the pricker on the cardboard, the pricker is then used to mark off the exact distance, and the line pencilled in. This method of working is strongly advised with a cardboard protractor, as the edge of the ruler is of necessity some little distance away from the plotting paper, and difficulty is experienced in drawing a straight line with the edge of the ruler, which is avoided by working in the manner last described.

It will be evident that one meridian line can only be used for plotting over a limited area of paper with a cardboard protractor, and when the plotting has proceeded up to the limit, a fresh meridian line parallel to the first must be drawn in order to continue the work. In order to avoid an excessive number of meridian lines, the range over which any particular one may be utilised for plotting can be increased by drawing lines on the protractor itself, parallel to the north and south lines on the latter, and at intervals of about an inch. The lines are drawn to the extreme edges of the cardboard, so that any one of them may be utilised for setting the protractor on the paper. With the usual size of cardboard on which the protractors are printed, it is thus rarely necessary to draw meridian lines on the plan closer than about 2 feet.*

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* See note by Mr. R. F. Percy, *Trans. Inst. Min. Eng.*, vol. xii., 1897, p. 585.

Plotting by Chords or Sines.—This is a modification of the method of plotting with a protractor, and is seldom employed. In effect a protractor showing only the angles corresponding to the directions in a particular traverse is constructed. The azimuths occurring in the traverse are reduced to quadrant bearings by applying the following rules :—

RULES FOR CONVERSION OF AZIMUTHS INTO QUADRANT BEARINGS.

If azimuth is between

0° *and* 90°,	*the numerical value is the same*	*and bearing is in*	*N.E.*	*quadrant*
90° ,, 180°,	,, = 180° — *azimuth*	,,	*S.E.*	,,
180° ,, 270°,	,, = *azimuth* — 180°,,	,,	*S.W.*	,,
270° ,, 360°,	,, = 360° — *azimuth*	,,	*N.W.*	,,

From a table of chords giving the latter to unit radius, the chords corresponding to the quadrant bearings are ascertained for a radius of 1,000 by moving the decimal point in the numbers given in the tables three places to the right. The example given on p. 220 illustrates the method of reducing the notes.

A circle of 1,000 units radius is drawn to any convenient scale on the plotting-paper, and a meridian line drawn through the centre of the circle, the intersections with the circumference being marked north and south points, and from one or another of these, according to the designation of the bearing, the length of the chords are marked off on the circumference of the circle in the respective quadrants, this being done either by means of a pair of compasses or simply by the scale to which the circle was drawn. Lines drawn from the centre of the circle to the intersections of the chords with the circumference represent the directions of the corresponding lines in the traverse. Thus, taking the first line in the example, the compasses are set to a distance of 1,030 units on the same scale with which the radius was measured, the point of the compasses being put in at the north point of the circle; the intersection with the circumference of the circle in the N.W. quadrant is then marked. A line drawn from the centre of the circle to the mark gives the direction of the first line of the traverse.

The plotting of the traverse is then carried out with the aid of the parallel ruler exactly as with a protractor, and to any scale irrespective of that used for plotting the chords.

SURVEY OF LONG-WALL WORKINGS AT A SCOTTISH COLLIERY.

No. 10 Pit. From centre of shaft, 12 ft. × 6 ft.; long side bearing S. 18° E.

No.	Azimuth Angle.	Quadrant Bearing.	$r=1000.$	Distance.	Remarks.
				Links.	
A	298° 00′	N. 62° 00′ W.	1030·0	116	.. ..
B	299° 30′	N. 60° 30′ W.	1007·5	47	.. ..
C	320° 00′	N. 40° 00′ W.	684·0	71	.. ..
D^2	315° 00′	N. 45° 00′ W.	765·3	..	bearing only, into air course.
D	227° 30′	S. 47° 30′ W.	805·4	151	into stone drift.
E	228° 00′	S. 48° 00′ W.	813·4	59	.. ..
F	301° 00′	N. 59° 00′ W.	984·8	86	.. ..
G	297° 30′	N. 62° 30′ W.	1037·5	45	.. ..
H^2	20° 00′	N. 20° 00′ E.	347·2	100	.. ..
J^2	14° 30′	N. 14° 30′ E.	252·3	45	.. ..
K^2	42° 30′	N. 42° 30′ E.	724·8	66	to face lying N. 68° W.
H	319° 00′	N. 41° 00′ W.	700·4	103	.. ..
J^2	16° 00′	N. 16° 00′ E.	278·3	58	.. ..
K^2	10° 30′	N. 10° 30′ E.	183·0	45	.. ..
L^2	10° 15′	N. 10° 15′ E.	178·6	97	.. ..
M^2	40° 00′	N. 40° 00′ E.	684·0	43	.. ..
N^2	55° 30′	N. 55° 30′ E.	931·2	23	to face lying S. 30° E.
J	313° 00′	N. 47° 00′ W.	797·4	95	.. ..
K^2	20° 00′	N. 20° 00′ E.	347·2	68	.. ..
L^2	9° 30′	N. 9° 30′ E.	165·6	117	.. ..
M^2	8° 00′	N. 8° 00′ E.	139·5	44	.. ..
N^2	20° 30′	N. 20° 30′ E.	355·8	35	10 links to face, lying N. 58° W.
K	304° 00′	N. 56° 00′ W.	938·9	101	.. ..
L^2	13° 30′	N. 13° 30′ E.	235·0	100	.. ..
M^2	355° 00′	N. 5° 00′ W.	87·2	99	to face running E. and W.
L	290° 00′	N. 70° 00′ W.	1147·1	87	.. ..
M^2	1° 00′	N. 1° 00′ E.	17·4	64	.. ..
N^2	348° 00′	N. 12° 00′ W.	209·0	70	to face lying S. 65° W.
M	278° 00′	N 82° 00′ W.	1312·1	49	.. ..
N	266° 00′	S. 86° 00′ W.	1363·9	29	.. ..
O^2	349° 00′	N. 11° 00′ W.	191·6	52	.. ..
P^2	332° 00′	N. 28° 00′ W.	483·8	28	to face lying N. 60° S.
O	261° 00′	S. 81° 00′ W.	1298·8	94	.. ..
P^2	2° 00′	N. 2° 00′ E.	34·9	50	to face lying S. 89° E.
P	261° 30′	S. 81° 30′ W.	1305·5	38	to end of level.

Plotting Colliery Surveys in Scotland.—In the West of Scotland, a method of plotting colliery surveys, which differs from that in vogue in other districts, is frequently employed. The protractor used consists of a circular brass plate, 2 feet in diameter, pivoted at the centre, so that it can rotate in a horizontal plane. It is supported in a square mahogany frame, the surfaces of the frame and of the protractor being flush. A brass or steel straight-edge is attached to one side of this square frame. The drawing-paper is used in circular sheets, which are fastened on the face of the protractor inside the graduated circle. A sheet of paper is permanently glued on, and sheets may be attached to this by means of wafers as required. A T-square replaces the parallel ruler used in other methods of plotting with the protractor. It is brought to the diameter of the protractor, and then the required bearing is brought under the edge of the T-square by rotating the protractor. The protractor is then held steady, while the T-square is moved along the straight edge attached to the mahogany frame in order that a line may be drawn through a station point. In the more recent forms of this instrument, an index line is engraved on a small piece of brass fixed on the left of the mahogany frame, and the required bearing on the protractor is brought to this line by rotation. A day's survey having been plotted, a tracing is made and transferred to the main plan of the colliery.

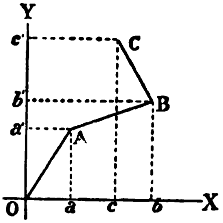

Fig. 88.

Plotting by Rectangular Co-ordinates.— This is the most accurate method of plotting a survey, because the position of each station is plotted without being affected by any errors committed in plotting previous stations.

It consists in assuming two fixed *axes*, O X and O Y, crossing at right angles at a fixed point or *origin*, O, and in calculating the perpendicular distances, or *co-ordinates*, of each station from those axes. When the direction of the true meridian has been ascertained, it is advisable to make one of the axes represent it. Thus, in Fig. 88, let O A represent a horizontal line surveyed. Through the starting point O, draw a north and south line, O Y, and at right angles to this, through the same point, an east and west line, O X, then the angle Y O A will represent the bearing of the line O A. The line O Y is taken as abscissa axis, and the line O X as ordinate axis. From the end point of the given line, O A, the two perpendiculars A a and A a' are let fall to those axes. A a is termed the *latitude* and A a' the *departure* of the line O A. The latitude of a point may be defined as its distance north or south of some parallel of latitude. The distance that one end of a line is due north or south of the other end, is called the difference of latitude of the ends of the line, or, briefly the latitude of the line, or its *northing* or *southing*. Similarly the distance which one end of a line is due east or west of the other end is called the difference of longitude of the ends of the line, or the *departure* of the line, or its *easting* or *westing*.

On regarding the right-angled triangles O A a and O A a' in Fig. 88, it will at once be seen that the latitude and departure may be calculated from the length O A and the bearing A O a' or β. Now a' A is equal to O a, and a' O is equal to A a; it is therefore evident that $\frac{\mathrm{A}\,a'}{\mathrm{O\,A}} = \sin\beta$, and consequently $\mathrm{A}\,a' = \mathrm{O\,A}\sin\beta$, and $\mathrm{O}\,a = \mathrm{O\,A}\sin\beta$. Similarly $\mathrm{O}\,a' = \mathrm{O\,A}\cos\beta$, and $\mathrm{A}\,a = \mathrm{O\,A}\cos\beta$. In other words, to find the latitude of the end point of any line, multiply its distance by the cosine of its bearing, and to find its departure, multiply its distance by the sine of its bearing. If the forward bearing of the line is northward, its latitude is north and is regarded as positive. If the forward bearing of the line is eastward, its departure is east, and is regarded as positive. West departures and south latitudes are regarded as negative magnitudes.

In Fig. 88, let O Y represent the meridian, and let O A B C represent a mine road, the survey of which gave the following results:—

Line.	Azimuth.	Distance.
		Links.
O A	32° 15′	176
A B	72° 32′	180
B C	331° 45′	155

The quadrant bearings must then be calculated from the rules given on p. 219. They will be found to be as follows:—O A, N. 32° 15′ E.; A B, N. 72° 32′ E.; B C, N. 28° 15′ W. The latitudes and departures may then be obtained from the formulæ—

Latitude = Distance × cos bearing,
Departure = Distance × sin bearing.

The troublesome and tedious multiplication by natural sines and cosines may be avoided by using logarithms. The calculations will then be as follows :—

			Departures.			Latitudes.
O A.	log 176	=	2·245512	log 176	=	2·245512
	L. sin 32° 15′	=	9·727227	L. cos 32° 15′	=	9·927230
			1·972739			2·172742
	Easting	=	93·91	Northing	=	148·85
O B.	log 180	=	2·255272	log 180	=	2·255272
	L. sin 72° 32′	=	9·979499	L. cos 72° 32′	=	9·477339
			2·234771			1·732611
	Easting	=	171·70	Northing	=	54·02
O C.	log 155	=	2·190331	log 155	=	2·190331
	L. sin 28° 15′	=	9·675154	L. cos 28° 15′	=	9·944922
			1·865485			2·135253
	Westing	=	73·36	Northing	=	136·54

In making calculations with logarithms, it must be remembered that in tables of logarithmic sines and cosines, the logarithm of the assumed radius is 10·000000. Consequently in the preceding calculations, the log. radius 10 is deducted in order to give the log. of the natural number sought.

The results of the calculation should be entered in the first four columns, for northing, southing, easting, and westing respectively in the table shown on p. 224.

Regarding the northing as positive and the southing as negative, the algebraical sum of the latitudes is 339·41 links. The easting being positive, and the westing negative, the algebraical sum of the departures is 265·61 — 73·36 = 192·25 links.

Before the calculated co-ordinates can be used for plotting purposes, the total latitudes and the total departures must be calculated. This is done by taking the algebraical sum at each station, and entering the results in the last four columns. A check on the algebraical addition for obtaining the total co-ordinates is afforded by obtaining the totals of the columns for the separate co-ordinates, and the differences between the totals should be identical with the total co-ordinates entered for the last line.

Having prepared this table, draw a meridian line through the first station O, Fig. 88. Along the meridian, north latitudes

Line.	Quadrant Bearing.	Distance.	LATITUDE.		DEPARTURE.		TOTAL LATITUDE.		TOTAL DEPARTURE.	
			N. +	S. −	E. +	W. −	N. +	S. −	E. +	W. −
O A	N. 32° 15′ E.	Links. 176	148·85	..	93·91	..	148·85	..	93·91	..
A B	N. 72° 32′ E.	180	54·02	..	171·70	..	202·87	..	265·61	..
B C	N. 28° 15′ W.	155	136·54	..	..	73·36	339·41	..	192·25	..
			339·41	..	265·61 73·36 192·25	73·36	..	..	..	..

are set off upwards, and south latitudes downwards. East departures are set off perpendicularly to the right, and west departures perpendicularly to the left. Set off, therefore, along the meridian in a northerly distance the latitude 148·85 links to the scale required. This gives the point *a′*. From that point, set off perpendicularly to the right the departure 93·91 links. The station A is thus fixed on the plan. Join the points O and A. From O again set off upwards 202·87 links to *b′*, and from that point set off 265·61 links perpendicularly to the right. This gives the point B. Join the points A and B. From O again set off upwards the latitude 339·41 links to *c′*, and from that point set off the departure 192·25 links. The last point C is thus fixed.

In this way any survey may be plotted with great ease and rapidity, and with greater accuracy than is possible by any other method.

The calculated co-ordinates are of great value for testing the accuracy of a closed traverse. Obviously, when a surveyor makes a circuitous survey returning to the starting point, he goes exactly as far to the north as he returns to the south, and as far to the east as he returns to the west. Consequently, if his survey is correct, the sum of the northings should be equal to that of the southings, and the sum of the eastings equal to that of the westings.

An illustration of this is afforded by the survey of a closed polygon with a theodolite, the notes of which are given on p. 176. On calculating the co-ordinates, the results on p. 226 are obtained.

The determination of the co-ordinates affords the most practicable method of distributing the errors in a closed traverse. It has been already pointed out (p. 169) that the total error in the angular measurements in a closed traverse can be ascertained if the "closing angle" has been measured. This information is generally only of practical use for determining whether it is necessary to repeat the angular measurements in the case of a traverse having an excessive closing error. Considering a traverse as having a fixed starting point, the effect of an error in measuring any angle on the accuracy of a traverse depends upon the position of the angle in relation to the starting point, as the effect of the error is cumulative; it is thus quite possible to *increase* the closing error of the traverse by distributing a total angular error between all the angular measurements.

The magnitude of the closing error is calculated from the errors in the total latitude and departure by the formula $e=\sqrt{l^2+d^2}$. in which e is the error of closure, l is the error of latitude, and d

Line.	Quadrant Bearing.	Distance.	LATITUDE.		DEPARTURE.		TOTAL LATITUDE.		TOTAL DEPARTURE.	
			North +	South –	East +	West –	North +	South –	East +	West –
		Links.								
1	S. 58° 33′ E.	1,091	..	569·5	931·3	..	..	569·5	931·3	..
2	N. 39° 03′ E.	252	195·5	..	158·8	..	..	374·0	1090·1	..
3	N. 68° 04′ E.	196	73·1	..	182·0	..	..	300·9	1272·1	..
4	N. 47° 44′ E.	534	358·9	..	395·3	..	58·0	..	1667·4	..
5	N. 63° 16′ E.	384	172·5	..	343·1	..	230·5	..	2010·5	..
6	N. 31° 13′ W.	336	287·1	..	..	174·0	517·6	..	1836·5	..
7	N. 59° 06′ W.	1,055	541·3	..	..	904·5	1058·9	..	932·0	..
8	S. 44° 28′ W.	771	..	550·5	..	539·5	508·4	..	392·5	..
9	S. 31° 29′ E.	154	..	131·4	80·5	..	377·0	..	473·0	..
10	S. 51° 29′ W.	605	..	377·0	..	473·0	..	..	..	..
..	..	..	1628·4	1628·4	2091·0	2091·0	..	..	..	..

the error of departure. The proportion which this error bears to the total perimeter p of the survey forms a good test of the accuracy of the work. If the ratio $e : p$ does not exceed 1 : 3000, the survey may be looked upon as satisfactory for most purposes; in Prussia the maximum admissible error is determined by the following formulæ :—*

For work under favourable conditions, $e < 0{\cdot}01\sqrt{4p + 0{\cdot}005p^2}$

For work under average conditions, $e < 0{\cdot}01\sqrt{6p + 0{\cdot}0075p^2}$

For work under unfavourable conditions, $e < 0{\cdot}01\sqrt{8p + 0{\cdot}01p^2}$

It will be seen that this limit is a comparatively high one. In most cases the surveyor himself will have to decide what is the permissible limit of error, having regard to the purposes for which the survey is required.

If the ratio $e : p$ falls within the admissible limits, the errors of latitude and departure are best distributed, so as to bring the total latitude and departure of the end of the last traverse to zero. This may be done in several ways, two of the simpler of which are the following :—

(1) Multiply the length of each draft of the traverse in turn by $\frac{l}{p}$, the product being the correction which must be added to or subtracted from the latitude of the end of the draft in question, in order to get a corrected latitude; in the same way each traverse must be multiplied by $\frac{d}{p}$, in order to obtain a correction to be applied to the respective departures; the correction must be added or subtracted according as the closing error is $-$ or $+$; from the co-ordinates thus corrected the total latitudes and departures are calculated in the usual way.

(2) Let L be the arithmetical sum of all the latitudes, and D of all the departures, these being added up without regard to their algebraical signs; each latitude is multiplied in turn by $\frac{l}{L}$, and each departure by $\frac{d}{D}$, the products being the corrections that must be applied as before to the co-ordinates of each traverse station.

The former is, generally speaking, the better method, as strictly the latter should in its turn be considered as modifying the azimuths to some extent, though in all ordinary surveys the effect is quite negligible. There are various other methods in use for distributing the error amongst the co-ordinates, but the above are sufficient for all ordinary purposes.

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* This information, together with the following methods of distributing the errors, is taken from Louis' and Caunt's "Traverse Tables," published by Edward Arnold.

It must not be forgotten that the distribution of a closing error does not of necessity eliminate the error at each point, and that it is quite possible that the corrected co-ordinates of any point (except the last one) may be further from the true value than were the uncorrected figures; hence these methods of distributing the closing error are strictly limited to surveys, the closing errors of which fall within the admissible limits.

One of the most important applications of co-ordinates is that to the determination of directions and distances for driving headings, and the location of points for the excavations of shafts, either by sinking or rising, the determinations being independent of any errors of plotting. The direction and distance of the line between a point of origin and any other point whose co-ordinates with reference to it have been calculated, may be determined by using the following formulæ:—

$$\text{Tan of bearing} = \frac{\text{departure}}{\text{latitude}}.$$

$$\text{Distance} = \sqrt{\text{lat}^2 + \text{dep}^2} \text{ or } \frac{\text{latitude}}{\text{cos. of bearing}} \text{ or}$$

$$\text{latitude} \times \text{sec. of bearing}.$$

These formulæ can also be applied to the determination of the direction and distance of the line between *any* two points whose co-ordinates with reference to a common point of origin are known, by assuming one of the two points as itself a point of origin and computing the co-ordinates of the second point with reference to it by the addition or subtraction of the respective co-ordinates given. Take as an example the table given on p. 224, assuming that it is desired to find the co-ordinates of C with reference to A, with a view to determining the direction and distance of A C.

Departure of C with reference to A $= 339{\cdot}41 - 148{\cdot}85 = +190{\cdot}56$.
Latitude „ „ $= 192{\cdot}25 - 93{\cdot}91 = +98{\cdot}34$.

The correct algebraical signs are readily determined by inspection. By using these values in the formulæ given the direction and distance of A C can be found.

Several examples of the use of the formulæ are given on p. 362 and following pages.

South African Practice in Calculating Co-ordinates.—The method of calculating co-ordinates in general use in mine-surveying in South Africa differs from that prevailing in most of the other mining centres. In the first place, instead of measuring the angles from a meridian line, they are measured from a reference line running due west, so that the whole-circle bearings of lines running due north, east, and south have magnitudes of 90°, 180°, and 270° respectively. The magnitudes of the angles when stated as quadrant bearings increase from zero for the west and east lines to 90° for the north and south lines.

The co-ordinates of a point in a survey are expressed with reference to a given point of origin, as the x and y of the point, the y of a point corresponding to its latitude in the system previously described and the x to its departure. Algebraical signs are used to distinguish the co-ordinates in opposite quadrants; thus values of y in the north quadrants are regarded as positive, those in the south as negative; values of x in the west quadrants are regarded as positive, those in the east as negative. The co-ordinates are usually calculated from seven figure logarithms from the following formulæ :—*

$$y = \text{distance} \times \sin \text{ of quadrant bearing.}$$
$$x = \text{distance} \times \cos \text{ of quadrant bearing.}$$

Co-ordinate Protractor.—This instrument, which is called a *trigonometer* by the makers, Messrs. Keuffel & Esser of New York, has been introduced in America. It consists of a plate 15 inches square (Fig. 89), divided into 100 equal squares by horizontal and vertical lines. It is provided with an arm fastened with its zero upon the zero at one corner of the plate. It is graduated, with the same division as the plate, to read distances from the centre outwards. On the sides, the plate has angular graduations, the zero joint being the centre of the quadrant. By moving the arm to the given angle, the latitude is at once read off on the vertical scale and the departure on the

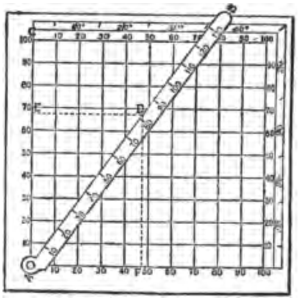

Fig. 89.

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* Details of the form of entry for these and other calculations are given in a paper on "Notes on Mine-Survey Records and Calculations," by Messrs. Priest and Whyte, *Trans. Inst. Min. and Met.*, vol. xxiii.

horizontal scale, for the given length as read on the arm. If, for instance, B A C is the given angle, and A D the given distance, D E and D F are the co-ordinates. The readings are exact to within 0·1 per cent. The instrument is also of use for calculating the bases and perpendiculars of inclined station-lines in mine-surveys.

Though described in 1886 by Mr. E. G. Gaertner * as a new invention, this instrument was known two hundred years previously. It is, I find, described on p. 127, and figured on plate 7 of Nicolaus Voigtel's *Geometria Subterranea*, published at Eisleben in 1686.

Calculating Scales.—For ordinary practical work the co-ordinates may be determined with great rapidity by means of the slide rule. On this rule, logarithms of numbers, sines, and cosines are represented graphically in the form of scales. The instrument consists of a rule, having on its face a groove cut throughout its entire length, in which a second rule slides smoothly. The bearing and length of a given line being known, its departure is found by setting 1 on the slide to the length on the rule, and against the sine on the slide will be found the required departure on the rule. Latitudes are found in a similar way, the cosines being read off by reading the sines backwards. To avoid this operation, complementary figures may be pencilled along the line of sines.

Very accurate slide rules are made by Gravét, of Paris. One 26 centimetres long is accurate to one part in 500. Co-ordinates of the lines occurring in mine-surveys may thus be determined accurately to the first place of decimals. The back of the slide is divided for sines, tangents, and logarithms, all of which can be read at the back through special openings without removing the slide, or the slide may be reversed. A sliding index, or *cursor*, is provided, which adds materially to the power of the instrument. For important theodolite surveys, the slide rule is not accurate enough. For this work, however, it saves much time in calculating differences of logarithmic sines, etc. The most accurate slide rule available is of the Gravét type with the graduations on celluloid. Careful tests of this instrument show that the average error in calculating co-ordinates is 0·12 per cent. The errors are consequently inappreciable when the survey is plotted to any of the scales usually employed for mine-plans.

With the celluloid slide rule, and other rules of the Gravét type, the departure of a given line in the survey may be found by placing the given angle as shown on the line of sines, against the index at the back of the rule, and by reading off the number, on the scale on the face of the slide, corresponding with the given distance, as shown on the upper scale. The latitude is found in a similar way, the cosine being used in place of the sine. In this way results may easily be found without calculation, accurate to the first place of decimals.*

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* *Trans. Amer. Inst. M.E.*, vol. xiv., p. 180, 1886.

In the Government Mining Offices on the Continent, calculating machines are extensively used for computing the co-ordinates of mine-surveys. The type of instrument generally used is that invented by M. Thomas, of Colmar, in Alsace. This instrument has recently been improved by Mr. Edmondson and by Mr. Tate. Full descriptions of the three instruments are given by Mr. C. V. Boys.†

Traverse Tables.—Tables which show by inspection the amount of the latitude and departure for any bearing and distance are termed traverse tables, because by their aid the resolution of traverses is effected without calculation.

In order to be of any use to the mine-surveyor, such tables must be calculated for every minute of bearing and to four places of decimals. These conditions are fulfilled by the tables calculated by H. Louis, J. T. Boileau, W. Crellin, and R. L. Gurden. There are several other tables published, which, though well arranged, are not sufficiently in detail for mine-surveying purposes. For example, the traverse tables given in Chambers's Mathematical Tables are calculated only for every degree of bearing to one place of decimals. Though valuable for problems in navigation, they are useless for mine-surveying purposes.

The following example will illustrate the method of using Louis' or Boileau's tables, which are calculated for every minute and to 5 decimal places for distances of 1 to 10:—Given the bearing of a line, N. 32° 15′ E., and its length 1 chain 76 links, required its latitude and departure. Seek the table headed 32°, and from the section 15′, take out the latitudes and departures separately for the hundreds, tens, and units, removing the decimal point in each case as many places to the right as the figures in each separated portion of the distance exceed those in the corresponding numbers in the tabular distance columns. The distance 1 chain 76 links will be separated into 100, 70, and 6 links, and the traverses for each will be taken out separately, thus:—

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* *Colliery Guardian*, p. 587, 1889.

† *Journ. Soc. Arts*, vol. xxxiv., p. 384, 1886.

Reduced Bearing.	Distance.	Latitude.	Departure.
N. 32° 15′ E.	100	84·5727	53·3614
	70	59·2009	37·3530
	6	5·0743	3·2016
	176	148·8479	93·9160

The most accurate traverse tables published are those computed by Mr. R. L. Gurden,[*] Authorised Surveyor for the Governments of New South Wales and Victoria. These tables are calculated to four places of decimals for every minute of angle up to 100 of distance, so that the sines and cosines for a distance of 12 miles may be ascertained correctly to within half an inch.

In the example given above, the latitude and departure are found with Gurden's tables, thus—

Reduced Bearing.	Distance.	Latitude.	Departure.
N. 32° 15′ W.	100	84·5728	53·3615
	76	64·2753	40·5547
	176	148·8481	93·9162

Only one opening of the traverse tables is required. With logarithms, on the other hand, the book has to be opened in four places, two separate additions have to be made, and in taking out natural numbers proportional parts have to be resorted to in order to find figures of the second place of decimals. The advantage of these traverse tables over logarithms, both as regards simplicity and economy of labour in calculation, is thus apparent.

In important undertakings it will be found advisable to calculate the co-ordinates by logarithms, and repeat the calculation by the traverse tables, so as to obtain an independent check and verification.

If the traverse tables are employed for calculating co-ordinates by the South African method, it should be noted that the departure columns give the figures for y and the latitude columns those for x, as the corresponding quadrant bearings are the complements of those in the general method.

Plotting Triangulation Surveys.—The sides of the triangles having been computed, the plotting may be carried out in the same way as that of the main lines of a chain-survey (see p. 213 *et seq.*). The accuracy of the plotting by this method, however, is not consistent with the accuracy of the field work in the case of triangulation surveys, and it is advisable to use the method of co-ordinates.

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[*] Published by Charles Griffin & Co., Ltd.

Calculating the Co-ordinates of a Triangulation.—This may be performed in several ways. Having computed the sides, the exterior lines of the triangulation may be considered as a closed traverse, the azimuths in which are determined from the observed angles.. The co-ordinates are calculated from seven-figure logarithm tables, the logarithms of the distances being the same as those obtained in computing them previously, and the point of origin should be selected in such a way that the total co-ordinates have either all positive or all negative values. The total co-ordinates having been adjusted for any closing error, the co-ordinates of the interior points in the triangulation may be calculated by considering them as stations in connecting traverses between convenient exterior stations. Thus in South Africa, where triangulation is exclusively used for surveys of mine concessions, it is usual to plot by co-ordinates. For the calculations necessary, C. L. H. Max. Jurisch's "Tables of natural sines and cosines to seven decimal figures of all angles between 0° and 90° to every 10 seconds with proportional parts for single seconds" (Cape Town, 1884), are chiefly used. The problem occurring is as follows:—Given the co-ordinates of two points, P and Q, the angles of direction x P Q or x Q P, the distance P Q and by observation, the angles of the triangle P Q R; required the co-ordinates of R. From the given data the distance P R and Q R and their angles of direction x P R and x Q R may be calculated.

Consequently—

$$
\begin{aligned}
&\text{P R} \sin x\,\text{P R} = y - \text{distance of R from P} = \Delta\, y \\
&\text{P R} \cos x\,\text{P R} = x - \text{distance of R from P} = \Delta\, x \\
&\text{Q R} \sin x\,\text{Q R} = y - \text{distance of R from Q} = \Delta'\, x \\
&\text{Q R} \cos x\,\text{Q R} = x - \text{distance of R from Q} = \Delta'\, x \\
&y \text{ of P} + \Delta\, y \quad = y \text{ of R};\ x \text{ of P} + \Delta\, x = x \text{ of R} \\
&y \text{ of Q} + \Delta' y \quad = y \text{ of R};\ x \text{ of Q} + \Delta' x = x \text{ of R.}
\end{aligned}
$$

It is usual to calculate the co-ordinates of R from both equations, in order to have a check on the calculations. In these equations, the co-ordinate drawn from any point parallel to the vertical or y axis is briefly called the y of that point, and the other co-ordinate is called the x of that point.

The following example, given by Leopold Marquard ("Co-ordinate Geometry," Cape Town, 1882), will illustrate the manner in which the calculations are made :—

	Lines.	Cape Roods.	Angles.
Given	A B =	41·26	A B C = + 69° 54′
	B C =	37·98	B C D = + 134° 44′
	C D =	66·46	C D E = − 47° 12′
	D E =	118·30	D E F = − 87° 03′
	E F =	167·75	E F G = + 277° 13′
	F G =	148·55	

Required the co-ordinates of A, B, C, D, E, F, G.

The line A B having been selected as x axis and B as the origin, we have—

y of A = 0 ; x of A = + B A = + 41·26
y of B = 0 ; x of B = 0

Angle X B C = 69° 54′, to this is added B C D = + 134° 44′, and from the sum 180° is subtracted. When the angle of intersection of two lines and the angle of direction of *one* of them is known, the angle of direction of the other is found thus :—When the two angles have the same vertex, their algebraical sum is the required angle of direction, and when they have different vertices, their algebraical sum, either diminished or increased by 180°, as may be most convenient, will be the required angle of direction. Consequently—

Angle X C D = 24° 38′
Add C D E = − 47° 12′ and add 180°.

Then X D E = 157° 26′
Add D E F = − 87° 03′ and add 180°.

Then X E F = 250° 23′
Add E F G = + 277° 13′ and subtract 180°.

Then X F G = 347° 36′.

To determine the co-ordinates of C :—

log B C (37·98) =	1·5795550	log B C =	1·5795550
log sin X B C (69° 54′) =	9·9727092	log cos X B C =	9·5361286
	1·5522642		1·1156836

y of C = + 35·67 x of C = + 13·05

Similarly the co-ordinates of the other points will be found to be as follows :—

	y	x
D	+ 63·37	+ 73·46
E	+ 108·77	− 35·78
F	− 49·24	− 92·10
G	− 81·14	+ 52·98

Convenient forms for keeping the field-book and for noting the calculations have been drawn up by Mr. G. A. Troye.*

The co-ordinates may also be calculated, using the observed angles and the base-line measurement as the data without previously computing any of the other sides. The formulæ generally used, as also their application to traverse tables, are given in Louis' and Caunt's " Traverse Tables " (see footnote on p. 227).

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* *Trans. Inst. Min. and Met.*, vol. ix., 1901, p. 126.

CHAPTER XIV.

PLANE-TABLE SURVEYING.

Principles.—Plane-table surveying is a system applied to traversing or triangulation in which the methods employed differ fundamentally from those already described, in that the directions of the lines in the survey are determined graphically instead of by circular measurement. The plotting of the survey is usually carried on concurrently with the operations involved in the field measurements, the resulting plan being the only complete record of the survey.

The Plane Table.*—This instrument, which was invented in 1590, consists of a drawing board, fitted to a tripod provided with a levelling arrangement, and is so mounted that it can be rotated in a horizontal plane, a clamp being provided for checking the movement when desired. The size of the board varies considerably, a convenient size for most purposes being about 15″ × 12″.

In connection with the table a sighting arrangement known as an *alidade* is used, which in its simplest form consists as shown in Fig. 90 of a flat scale, fitted at either end with sight-vanes similar to those used on dials. An alidade of this description is quite efficient for many purposes, but much more elaborate forms are obtainable. In most of them the sight-vanes are replaced by a telescope, and a vertical circle for measuring vertical angles is provided, thus increasing the range of application of this system of surveying, as not only can distances measured on sloping ground be accurately represented, but the elevations of the various points can be determined and used for putting in contour lines. As applied to the plane table, the principal advantage of a telescope is the means it affords of determining distances optically, thereby considerably increasing the rapidity of working (see Chapter XVIII.). An alidade worthy of special notice is that designed by Mr. H. S. Gale, of the United States Geological Survey, and manufactured by the Bausch and Lomb Optical Company, in which a fixed prismatic eye-piece for observing from above is used; this should be a very useful innovation, as on occasions it is extremely difficult to take observations with telescopic alidades provided with the usual form of eye-piece.

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* Consult J. Pierce's paper on the economic use of the plane table, *Min. Proc. Inst. C.E.*, vol. xcii., 1888, p. 187.

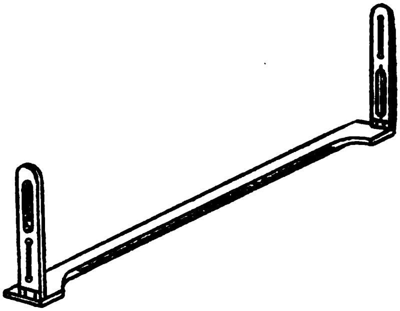

Fig. 90.

The general appearance of a telescopic alidade of modern construction is very similar to that of the instrument shown in Fig. 94. In this case, however, the sighting arrangement is simply a tube.

For centring the table over a given station a special form of plummet suspender for attaching the plummet directly below any desired point on the board is necessary, as it is not usually the centre of the board which has actually to be centred, but the point on it which represents the station. A very convenient form of clip for the purpose is shown in Fig. 91. When in use the clip is fixed on the table so that the point of the V is at the point on the paper which has to be centred.

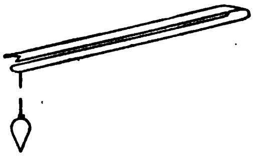

Fig. 91.

The levelling of the table is usually performed with the aid of a detachable spirit-level, the circular forms being very convenient.

The attachment of the paper to the board may be made by means of ordinary drawing pins, but some form of spring or screw clip will usually be found more convenient in case of the alidade coming into such a position as to necessitate the temporary detachment of the pin or clip at one or other of the corners.

Traversing with the Plane Table.—The usual method of procedure may be explained with reference to Fig. 92, in which the points A, B, C, and D represent the stations. The table is set up at, say, station A; in practice the point on the paper representing the starting point would be fixed first, and the point transferred to the ground by means of the plummet. After levelling the board, it is rotated so that the paper occupies the most advantageous position from the point of view of keeping the survey as central as possible on the paper, the position of the starting point being also chosen to effect the same object. The board having been clamped, a fine steel pin or needle is pushed into the paper at the starting point, and using this as a pivot, the alidade is turned until a signal pole placed at D is intersected by the cross-wires. A line is then drawn with the edge of the alidade from the starting point in the direction of D. The alidade is then directed towards B, and again using the needle at the starting point as a pivot, the alidade is set so that the cross-wires intersect a signal at B. A line is drawn from the starting point towards B. The position of the alidade should also be marked by means of a second steel pin pushed into the board as near to the edge of the paper as possible, so as to form the longest available bearing for setting the alidade when observing the back-sight at the next station. The distances from D to A and from A to B having been measured by means of a chain or tape, they are plotted off along the corresponding lines either by means of the scale on the alidade or an ordinary plotting scale. The table is now removed to station B, leaving a signal pole at A. It is set up with the aid of the special plummet suspender, which is set so that the point of the V coincides with the mark on the paper corresponding to station B. In order that the centring shall not be sensibly disturbed when taking the back-sight subsequently, it is advisable to keep the line representing A B on the paper as nearly as possible in line with A, so that a very slight movement will suffice for the final setting. The centring having been completed, the clamp is released, and having set the alidade in contact with the two pins inserted at the previous station, the table itself is turned until the cross-wires intersect the signal at A. The clamp is tightened and the pins taken from the paper, one of them being re-inserted at the point corresponding to station B, and using this as a pivot, the sight to C is taken in the manner described for fixing station B. The distance B C is measured and plotted, and the instrument is removed to C for the purpose of taking a check sight to D.

Offsets may be taken from the traverse lines and plotted as the survey proceeds; if they are very numerous they should be entered on separate sheets for the different lines, the sheet for each line being handed as completed to the table operator, who can proceed with the plotting as the chaining and offsetting of the next line is being carried on.

It will be seen that the method of traversing with the plane-table is analogous to the continuous reading method of fixed-needle traversing.

Triangulation with the Plane Table.—The plane table is rarely used for making extended triangulation surveys, its use in this connection being mainly confined to the fixing of points for filling in the detail of an area surveyed with the theodolite either by traversing or triangulation. The procedure may be illustrated by taking the same stations as in the previous case, the points for C and D being assumed for this purpose to be both visible from A and B. The line A B is taken as the base line which has been measured.

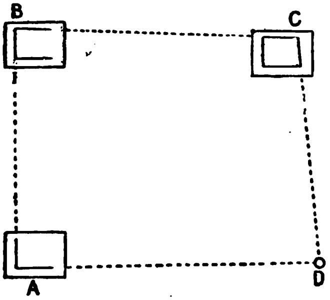

Fig. 92.

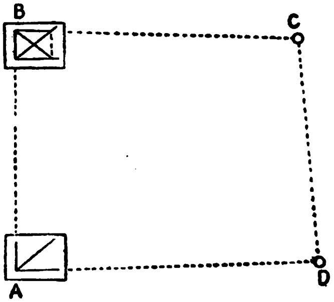

Fig. 93.

The table is set up at A, the position of the starting point having been selected as before and the table clamped. A pin is pushed into the starting point and sights taken with the alidade to D, C, and B, corresponding lines being drawn on the paper and distinguished by lettering. The distance of A B is plotted off and the table removed to station B. It is centred, and the alidade having been set to the line AB the table is rotated until the cross-wires intersect the signal at A. It is then clamped and sights taken by turning the alidade till the cross-wires intersect the signals at C and D successively, corresponding lines again being drawn. The intersections with the previous lines represent the positions of the respective stations in the survey, as will be evident from Fig. 93.

The method of triangulation is in practice usually combined with that of traversing, and for filling in the detail of a triangulation survey very satisfactory results can be obtained by traversing between the main stations, locating well-defined points from the traverse stations and sketching in the detail between the well-defined points.

Correlation of Plane-Table Surveys.—For the purpose of transferring plans made by plane-tabling to, say, a general plan of a royalty, it is necessary to determine the directions of the lines with reference to a common standard direction. When the magnetic meridian is the standard of direction the correlation is very readily made. A trough compass is generally used for the purpose, and one constructed with one of the longer sides of the box accurately parallel with the central axis is necessary. The meridian may be drawn on the plan at any station free from local disturbance. The trough compass is laid down after a backsight to bring the board into the correction position for proceeding with the usual sighting has been taken, and the table has been clamped; the needle of the compass is set free to oscillate, and the box is then turned gently round until the needle coincides with the zeros of the scales at either end. A line is then drawn on the plan, using the " true " side of the box as a straight edge, and distinguishing the north end in some characteristic manner.

If the general plan is not referred to the magnetic meridian, it is advisable to start the plane-table survey from one end of a line which has been determined by the general survey. After the table has been set up and clamped a sight is taken to a signal on the line to obtain its representation on the paper, the starting point for the plane-table survey being at some point on this direction line so obtained.

The transference of the plane-table survey is effected by making a tracing and bringing the direction line on the latter to coincide with the corresponding direction line on the general plan, the starting point also being brought to coincide with its known position.

Occasionally it may be desirable to start the plane-table survey from an unknown point, in which case data to fix the starting point with reference to known points must be obtained; this is generally done by lining and measuring. The following method will sometimes be found useful where, say, three triangulation stations can be seen from the point at which it is desired to start the plane-table survey. The plane table is set up, and after clamping in position the starting point on the paper is selected, and from it sights are taken in turn to each of the three known stations, corresponding lines being drawn and distinguished by lettering. The survey is then continued in the usual manner. To locate the starting point on the general plan, the transferring tracing on which the three lines referred to are also drawn, is laid on the plan and manipulated so that the three lines, produced if necessary, simultaneously intersect the corresponding triangulation stations on the plan. When this condition is fulfilled the starting point is located, and moreover the whole tracing is in its correct relative position, and can be transferred forthwith. This method of locating the starting point is not possible when the four points involved lie on the circumference of a circle, and is only admissible when the conditions are widely divergent from this.

Underground Surveying with the Plane Table.—Provided that the workings are not too wet or unusually cramped, undergrourd surveying can be performed equally well with the plane table as with the miner's or vernier dial, with the advantage that beyond the making of a transferring tracing the surveyor's work is completed when he leaves the mine, and there need be no question of the accuracy of the survey or of the omission to make or note some indispensable measurement, necessitating a partial or entire repetition of the survey. Plane-tabling is not suggested as a method for replacing the theodolite, but as a means of expeditiously surveying between points determined by the use of the latter instrument, it is worthy of considerably greater attention than it has hitherto met with in general mine-surveying.

Before the introduction of the theodolite, the plane table was largely used for mine-surveying in Sweden, where the magnetic nature of the iron ore deposits renders the compass useless for surveying purposes.

In surveying mines in that country, the surveying instrument used consists of a sighting-tube attached to an alidade-rule, *a, b* (Fig. 94), provided with a tube, *c*, and a vertical graduated circle, *d*, both fastened to one and the same horizontal axle, in such a manner that the tube can move in the vertical plane which passes through one edge of the alidade, *a b*.

This sighting-tube, in surveying, is placed on a plane table fixed to a tripod frame, which at the top consists of a round brass ring, *a* (Fig. 95), whose upper edge is plane turned and

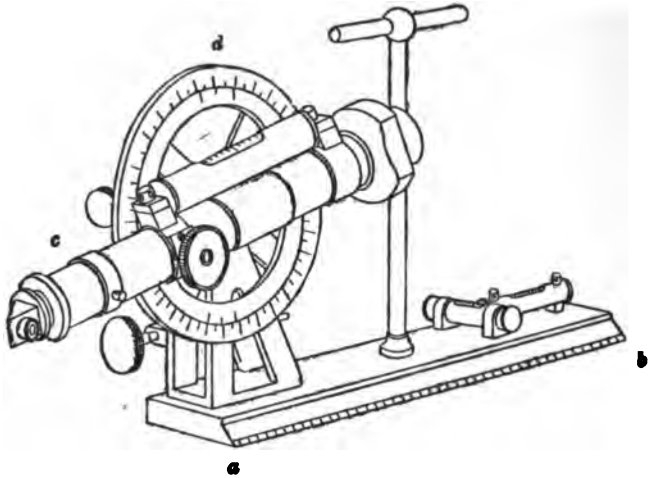

Fig. 94.

polished. In the interior of the ring is fitted a round wooden disc, *b*, supported by the screws *c*, and adjusted by the screws *d*,

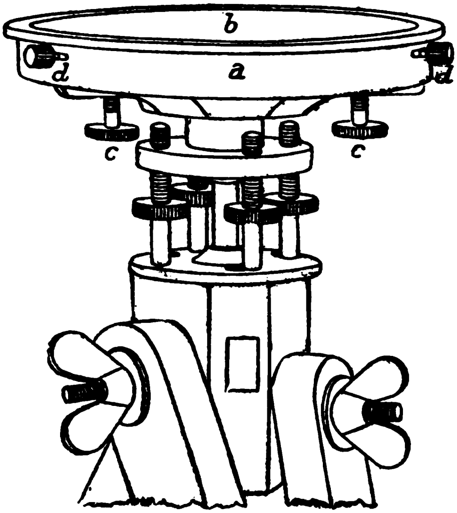

Fig. 95.

in such a manner that, when drawing-paper of somewhat smaller dimensions than the wooden disc is glued fast on the upper surface of the disc, the disc surface thus covered is close under the upper edge of the brass ring.

In surveying, at least two plane-tables are always used. From each station the immediately preceding and immediately following station is sighted, as well as all the fixed points situated between these stations and the contour-points in the excavation which is being surveyed.

In surveying station-points and fixed points, the lines of sight are marked on the paper on which the distance and the angle of the lines to the horizontal plane are noted. The contour-points are marked, with the help of a scale, direct on the paper, after the distance to them from the station has been determined. The plan of the mine is then made by combining all these different observations.

This method of surveying has, according to Professor G. Nordenström,* been in use in Sweden for more than 150 years. During the last thirty years many improvements have been made in these instruments, and since steel tapes have come into use in all more important surveys, very excellent results have been attained by this method. The instrument is also much more convenient to use than a theodolite in excavations of the form which is common in Swedish mines.

Prospecting Surveying with the Plane Table.—As far as mine-surveying is concerned, this is at present probably the most important application of the plane table. For this class of work a plane table about 12″ × 9″, mounted on a telescopic camera stand, is very suitable. The table should be provided with rollers at the end for the reception of a long strip of thin but tough drawing paper, fresh sections of the strip being brought into use as required. Provision should be made for clamping the rollers so that the paper on the board can be kept taut. The use of a light telescopic alidade fitted with subtense wires and used in conjunction with a collapsible levelling staff opening out to, say, 6 feet, renders a very rapid rate of working attainable, combined with an accuracy that is not usually associated with any form of compass-surveying for the same purpose. An outfit such as described has been found very satisfactory for the mapping of extensive magnetic iron-ore deposits in Scandinavia, the surveys being very rapidly conducted, and resulting in remarkably accurate plans, embodying the fullest desirable information.

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* *Journal of the Iron and Steel Institute*, vol. liv., 1898, p. 62.

The avoidance of complicated field notes is in itself sufficient to commend this method for prospecting work.

Combined Surveying and Plotting Instrument.—Henderson's rapid traverser is based on the plane-table system of surveying. By its aid, underground or surface surveys can be made, and the results laid down on paper with very great rapidity. Unlike the plane table, however, it is not intended that the rapid traverser should be used for plotting the survey in the field, this being done in the drawing-office, with the aid of a parallel rolling ruler and scale.

The instrument consists of a circular metal table of about 10 inches diameter, mounted on an ordinary tripod stand, with the usual adjusting screws. It is provided with a brass alidade, with an ordinary sight at each end, revolving round a fixed centre pin. Upon the face of the table a disc of celluloid is screwed, and over this the alidade, by means of a groove, can travel freely. The disc is divided into five or more concentric rings marked on the celluloid, and the feather-edge of the alidade is also divided by means of a rectangular notch at each ring, for the purpose of pencilling on the disc the line observed. By means of clamping screws, similar to those of the circumferentor, the disc can be clamped to the stand, and the alidade, with sights attached, to the table when required.

In traversing, the instrument is levelled and the alidade is sighted back to the starting point of the survey. Both the alidade and the table are then securely clamped. The direction of this first line of the survey is marked with a finely pointed HH pencil on the selected ring of the disc, at two points equidistant from the centre, and duly lettered or figured within the notch cut in the feather-edge of the alidade. Three tripods are used. Each of the two spare ones carries a candle-holder with levels attached, a white card replacing the candle in surface surveys. The alidade is next unclamped, sighted to the forward tripod, and clamped, the direction of the second line being marked on the celluloid as before. The instrument is then removed from its tripod and fixed, with the alidade still clamped, on the forward stand, and sighted back to the position it previously occupied and clamped. This having been done, the alidade is unclamped, sighted to the next forward station, again clamped, and the direction marked as before, the process being repeated for the remainder of the traverse. The magnetic meridian is taken at any convenient spot in the course of the traverse by means of a trough compass placed temporarily against the back edge of the alidade. The line thus given, pencilled on the disc, establishes the orientation of the whole of the survey.

The sights of the alidade are graduated to give angles of depression or elevation up to 25°. Thus, the instrument suffices for the majority of collieries, for the levels of metalliferous mines, and for all ordinary surface surveys. Where greater accuracy in vertical angles is required, as in inclined shafts, a vertical semicircle is attached to the alidade, and the angles read as with the theodolite.

In plotting the survey, the celluloid disc is unscrewed from its circular table and placed with the north line, that has been marked on it, in its proper position on the meridian line drawn on the intended plan. A rolling parallel ruler is then applied to each line of the survey in succession as shown on the disc, and marked off on the plan. In a large survey, the disc may be moved to any meridian line as required. For future reference, the disc itself may be preserved with the name and date of the survey recorded on it, or, if necessary, the magnetic bearings may be read off with the aid of a protractor and booked, when the celluloid disc may be cleaned for future use.

This instrument has been successfully used by the inventor, Mr. James Henderson, in numerous surveys of Cornish mines, notably at West Wheal Frances, at Redruth. In November, 1892, it was decided to put out a cross-cut south from the 174-fathom level so as to come under the perpendicular portion of Bailey's shaft, which was perpendicular only as far as the 60-fathom level, and then went off to the south following the underlie of the lode. After the cross-cut, which was 20 fathoms in length, had been driven, a rise had to be carried up through some 55 fathoms of ground to the bottom of the perpendicular portion of Bailey's shaft. In order to do this, the relative position of the two points was determined by surveying down 80 fathoms of the inclined portion of the shaft to the winze to the 174-fathom level, the total distance of levels surveyed amounting to 300 fathoms, and the number of stations required being fifty-three. The perfect holing on October 17, 1893, affords a guarantee of the adaptability of this instrument to complicated underground surveys.

An ingenious combined surveying and plotting instrument has been devised by Mr. T. Ferguson * in the form of a separate flat box adapted for fixing to the handle-bar of a bicycle, with which, whether ridden or trundled, the trace of the route can be

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* *Automatic Surveying Instruments*, London, 1904, p. 37.

made to develop as quickly as one proceeds. This cyclograph should prove of great value to the prospector, besides being useful for filling in detail in triangulation surveys. In the flat box fixed horizontally to the handle-bar of a bicycle is contained a sheet of drawing paper, which can be kept in constant orientation by adjusting meridian lines ruled on its surface parallel to a compass-needle mounted about 10 inches above the box. As the bicycle moves, the sheet of paper is gradually displaced in a backward direction, and a small ink-roller pressing on the paper marks a line in a forward direction. As the course changes in direction a simple manipulation maintains parallelism between the paper-meridians and the compass-needle, and a facsimile of the path followed develops under the eyes of the observer.

CHAPTER XV.

CALCULATION OF AREAS.

Measures of Area.—The area of mine-royalties and of coal wrought is usually expressed in acres. The *statute acre* is equal to 10 square chains or 100,000 square links. It is sub-divided either decimally or into 4 *roods* of 1,210 square yards, and 160 *perches* of $30\frac{1}{4}$ square yards. One square mile is equal to 640 acres.

In order to reduce square links to acres, roods, and perches, divide by 100,000 by cutting off five figures to the right hand. The figures remaining to the left will be *acres*. Multiply the remainder by 4; the whole-number remaining will represent *roods*. Multiply the remaining fraction by 40; the figures beyond the decimal point will be *perches*. The nearest round number is usually taken; fractions less than half a perch being disregarded.

The metric unit of land measure is the *hectare* of 10,000 square metres. This is equal to 2·4711 acres.

Three methods of measuring areas are employed: the method of triangles, the method of ordinates, and the mechanical method.

1. **Method of Triangles.**—The areas of the separate triangles in a survey made with the chain or by triangulation can be calculated from the measurements in the field notes by using one or other of the following formulæ, in which the respective sides are designated by the small letters, a, b, and c, and the angles opposite to them by the corresponding capitals.

Given the three sides $\Delta = \sqrt{s(s-a)(s-b)(s-c)}$. (*In this formula* s = *the semi-perimeter of the triangle.*)

Given two sides and the included angle $\Delta = \dfrac{a\,b\sin C}{2}$.

Given one side and two adjacent angles $\Delta = \dfrac{a^2 \sin B \,.\, \sin C}{2 \sin(B + C)}$.

The areas of the separate triangles having been found, the total area included by the exterior lines of the main system of triangles is found from the sum of the separate triangles. The area between the lines referred to and the boundary itself may be determined in some cases by the method of ordinates from the field measurements and added to, or subtracted from, the previous total as may be required. In other cases it is more convenient to calculate the area of this portion of the survey from measurements on the plan after plotting.

In scaling plans for calculating areas the plotting scale used for making the plan should be used, making allowances, if necessary, for the contraction or expansion of the paper by comparing the plotting scale with that drawn on the plan at the time it was made. In dealing with plans for which no corresponding plotting scale is available, the simplest procedure is to scale up from a scale of inches and calculate to square inches of area on the plan, then, after finding by calculation the area that, say, 1 square inch of plan represents on the ground, the conversion is simple.

For the calculation of areas from plans by the method of triangles the formula in universal use is $\Delta = \frac{a\,p}{2}$, in which a is any side of a triangle and p the perpendicular let fall from the opposite angle on to the side, or on to the side produced; calculations can readily be checked by repetition, using a different side and the corresponding perpendicular for the second calculation. The area on the plan is divided up into triangles and perpendiculars drawn. The triangles are numbered to facilitate reference, and it is advisable to enter lightly in pencil on the plan the measurements obtained in the scaling. Time is saved in the calculations by dealing with triangles in pairs, then taking the connecting line as the base, the area of the pair of triangles is obtained by multiplying the base by half the sum of the perpendiculars. A form of tabulation used extensively in calculating areas of coal worked, for the purpose of assessing royalty payments in the Yorkshire and Lancashire coalfields, is shown by the following entries, the first of which relates to a pair of triangles; the second to a single triangle.

Seam.............. District.............. Date..............

No. of Figure.	Base.	Perps.	Sum.	Average.	Area. Square Links.
1	288	138/74	212	106	30528
2	315	0/128	128	64	20160

In order to avoid an excessive number of small triangles when dealing with irregular boundaries, the process of equalising the boundary to reduce the number of sides is adopted. The usual method of equalising adopted is based on the method of reducing a polygon to a triangle having the same side, as shown in the following example, Fig. 96.

In this figure the polygon A B C D E is shown by the thick firm lines, and the method of construction to obtain the triangle A F G is as follows:—Produce C D at either end. Join A C and A D. Draw a line parallel to A C from B, meeting C D produced at F. Join A F. From E draw a line parallel to A D, meeting C D produced, at G. Join A G. The method depends upon Euclids' theorem that *triangles on the same base and between the same parallels are equal to one another.*

By using a parallel ruler and a pricker the drawing in of all the constructional lines, except the prolongation of the base, may be avoided and the method applied to practically any figure.

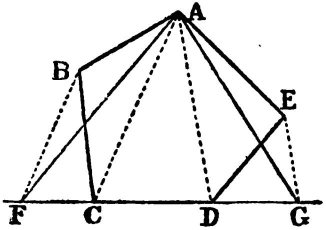

Fig. 96.

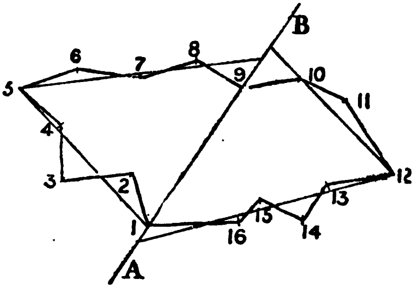

Fig. 97.

Thus, taking the case of the irregular boundary shown in Fig. 97. A base-line A B is selected and points marked off round the boundary such that the portions between successive marks may be regarded as straight lines. For convenience in explanation they have been numbered. The pricker is put in at, say, the point marked 1, the edge of the ruler is rolled to make contact with the pricker, and using the latter as a pivot, the edge of the ruler is brought into contact with the third point; the pricker is taken out and the ruler rolled until its edge is in contact with 2, and the pricker is reinserted in contact with the edge of the ruler on line A B. The ruler is turned round against the pricker till the edge also makes contact with point 4. The ruler is rolled to point 3, and the pricker reinserted, touching the edge of the ruler and on line A B. The ruler is turned to make contact with point 5, and then rolled back to 4, the pricker being reinserted on line

A B, and in contact with the edge of the ruler. This last prick-mark is joined to point 5, and represents a single equalising line replacing the four lines, 1-2, 2-3, 3-4, 4-5. Starting now from the points 9 and 7, an equalising line from 5 on to A B is again constructed. The portion of the figure on the other side of A B is now dealt with, using point 12 as the finishing point for equalising. The two triangles shown are together equal to the area of the irregular figure.

The method can be applied to boundaries in the form of a more or less uniform curve by marking off intervals between which for practical purposes the boundary may be considered as straight. The close approximations to the correct areas obtained by this proceeding can very easily be demonstrated by drawing circles to a definite radius and using a diameter prolonged as the base for equalising.

2. **Method of Ordinates.**—An axis A X is measured along the greatest length of the track to be measured (Fig. 98). Offsets are measured at right angles to that axis, sufficiently close together to make the spaces between them approximate to trapezoids. Let d be the distance along the axis between two adjacent offsets or ordinates, and b, b', the breadths of the figure at those ordinates. The area of the trapezoid is then $\frac{(b + b')\,d}{2}$, and the area of the whole figure is the sum of the areas of the trapezoids into which it is divided.

For example.—Let A X in Fig. 98 represent the chain-line from which offsets were taken to a curved fence. The lengths of the offsets measured in links, were as follows:—$b_0 = 30$, $b_1 = 38$, $b_2 = 61$, $b_3 = 50$, $b_4 = 85$, $b_5 = 80$, $b_6 = 40$, $b_7 = 60$, $b_8 = 69$, $b_9 = 48$, and $b_{10} = 19$. The area included between the chain-line and the fence is—

$$\begin{array}{rcl}
50 \times (30 + 38) & = & 3{,}400 \\
50 \times (38 + 61) & = & 4{,}950 \\
50 \times (61 + 50) & = & 5{,}550 \\
50 \times (50 + 85) & = & 6{,}750 \\
50 \times (85 + 80) & = & 8{,}250 \\
50 \times (80 + 40) & = & 6{,}000 \\
50 \times (40 + 60) & = & 5{,}000 \\
50 \times (60 + 69) & = & 6{,}450 \\
50 \times (69 + 48) & = & 5{,}850 \\
50 \times (48 + 19) & = & 3{,}350 \\
\hline
\text{Total,} & = & 55{,}550
\end{array}$$

Half this total—that is, 27,775—is the area in square links.

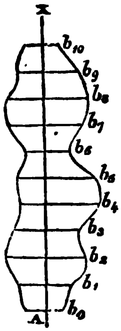

Fig. 98.

When the intervals between the offsets are all equal, as in the above example, the calculation may be considerably simplified. All the values of d being equal, the formula becomes

$$\text{Area} = \left(\frac{b_0}{2} + b_1 + b_2 + b_3 + \text{etc.} + \frac{b_n}{2}\right)d;$$

that is to say, the area is equal to the sum of all the intermediate offsets, and of one-half the end offsets multiplied by the constant interval between them. Applying this formula to the above example—

$$\text{Area} = (15 + 531 + 9\tfrac{1}{2}) \times 50 = 27{,}775 \text{ square links.}$$

When the line determined by the offsets is curved, the area may be calculated with greater accuracy by Simpson's formula. This assumes that the lateral boundaries of the figure consist of short parabolic arcs. An even number of equal distances must be measured along the axis, when the formula is

$$\text{Area} = \left\{ b_0 + b_n + 2(b_2 + b_4 + \text{etc.}) + 4(b_1 + b_3 + \text{etc.}) \right\} \frac{d}{3};$$

that is, the area is equal to one-third of the constant interval between the offsets multiplied by the sum of the first and last offsets, twice the sum of the even offsets, and four times the sum of the odd offsets. Applying this formula to the example given,

$$\text{Area} = (30 + 19 + 510 + 1104)\,\frac{50}{3}$$
$$= 27716\tfrac{2}{3} \text{ square links.}$$

By means of rectangular co-ordinates, the area enclosed by a traverse may be accurately calculated without necessitating the preparation of a plan. The general rule for finding areas by this method is as follows:—Multiply the total latitude of each station by the sum of the departures of the two adjacent courses. The algebraical half sum of these products is the area.

The total latitude of each station is found by adding the latitude of the preceding course to the total latitude of the preceding station. To find the adjacent departures, add the departures of the two courses, one on each side of the station. The following is an example of this method of calculation:—

No.	Bearing.	Distance.	Latitude.		Departure.		Total Latitude.	Adjacent Departures.	Double Areas.
			N. +	S. −	E. +	W. −			
A	N. 51° 33′ E.	29·18	18·14	..	22·85	..	..	..	..
B	S. 73° 07′ E.	12·30	..	3·57	11·77	..	+18·14	+34·62	+628·00
C	S. 20° 37′ W.	18·32	..	17·15	..	6·45	+14·57	+ 5·32	+ 77·51
D	S. 78° 45′ W.	25·40	..	4·95	..	24·91	− 2·58	−31·36	+ 80·90
E	N. 23° 26′ W.	8·21	7·53	..	..	3·26	− 7·53	−28·17	+212.12
..	..	..	25·67	25·67	34·62	34·62	..	..	998·53

The double area of the polygon is thus 998·53 square chains. The area, therefore, is 499·26 square chains, or 49·926 acres.

3. **Mechanical Method.**—Instruments for measuring areas on plans are termed *planimeters*. The form most generally used is the polar planimeter of Amsler, of which the general principle is shown in Fig. 99. This is an instrument for measuring the area of any figure, however irregular, by the mere passage of a tracer round its perimeter. It consists essentially of three parts, the adjustable arm C D, the polar arm B C of fixed length, and the rolling wheel F, which rests upon the plan. The wheel is graduated and provided with a vernier. The two arms of the instrument are hinged together by a hardened steel axis C, and permit of an angular motion of nearly 180°. The rolling wheel is mounted on a steel axis parallel to the adjustable arm C D—that is, parallel to the imaginary line joining the tracing point at D and the axis C of the polar arm. The number of complete revolutions of the rolling wheel are shown by a record disc driven by an endless screw on the shaft E. At the end of the arm B is a loaded disc which rests upon the table, and serves as a fixed support for the instrument. In its centre at B is an upright pin forming the turning point or pole of the whole instrument. At the end of the adjustable arm, at the same distance from it as the axis E, the tracing point D is screwed in vertically.

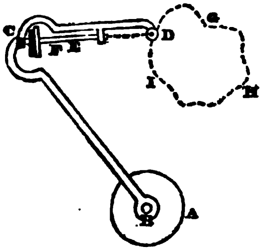

Fig. 99.

When the tracing point D is carried round the outline of any figure, such as G H I, so as to return to the point from which it started, it can be proved * that the distance rolled by the edge of the wheel F is equal to the area of the figure divided by C D, and consequently that the area of the figure is equal to C D multiplied by the distance rolled by the wheel F. In Great Britain and the United States, the graduations on the circle usually represent square inches of area on the plan.

This planimeter gives results sufficiently accurate for mining purposes, and its cheapness and simplicity render it of great value. It is not possible, however, always to obtain a very high degree of accuracy, as it is found that the planimeter is affected by the paper on which the measuring-wheel revolves. The instrument should never be used in such a position as to necessitate the roller passing over the edge of the paper on which a plan is drawn, and is practically useless on old mounted plans with cracks on their surfaces.

The drawbacks indicated to the use of polar planimeters are non-existent in the precision planimeters made by G. Coradi, of Zurich. In these instruments, the so-called *suspended planimeters* and *linear rolling planimeters*, the measuring wheel does not travel on the plan itself but on a disc, which is an integral part of the instrument.

The suspended planimeter is essentially a polar planimeter; it gives, however, results ten times more accurate than those given by Amsler's instrument. The linear rolling planimeter is the most accurate instrument of its kind yet invented. Instead of revolving round about a pole, the rolling planimeter moves in a straight line, on either side of which the area is determined.

The table on p. 254 showing the mean error in planimeter readings has been drawn up from the results of a series of experiments made by Professor Lorber of Leoben, in Austria.

The simplest of all area-measurers is the hatchet-planimeter.† This is merely a trammel of fixed length, with at one end, a tracing pointer, and at the other end, in the same plane, a curved knife-edge called the hatchet. The boundary of the figure, whose area is to be ascertained, is traced continuously in one direction, while the hatchet describes a path from which the area of the figure can be directly measured.

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* For proof, consult the report on this instrument by Sir Frederick Bramwell in *Rep. of Forty-second Meeting of the Brit. Assoc.*, p. 401. 1872.

† *Engineering*, vol. lvii., 1894, p. 687. See also O. Henrici's monograph, *Rep. Brit. Assoc.*, 1894, pp. 496-522.

Area.		The Mean Error in a Passage of the Tracer amounts to the following Fraction of the Area :—			
In Square Centimetres.	In Square Inches.	With the Polar Planimeter. Unit of Vernier 10 sq. mm, (0·015 sq. in.)	With the Suspended Planimeter. Unit of Vernier 1 sq. mm. (0·001 sq. in.)	With the Rolling Planimeter. Unit of Vernier 1 sq. mm. (0·001 sq. in.)	With the Rolling Planimeter. Unit of Vernier 0·5 sq. mm. (0·0005 sq. in.)
10	1·55	1 in 75	1 in 625	1 in 625	1 in 1,000
20	3·10	1 in 148	1 in 1,111	1 in 1,000	1 in 2,000
50	7·75	1 in 355	1 in 2,500	1 in 2,000	1 in 3,000
100	15·50	1 in 682	1 in 4,167	1 in 3,333	1 in 5,000
200	31·00	1 in 1,274	1 in 7,143	1 in 5,128	1 in 7,693
300	46·50	..	1 in 9,375	1 in 8,000	1 in 10,000

Produce of Coal-seams.—The area of coal wrought in any particular seam may be estimated by dividing the plan into squares of 10 acres each. It will be found useful to have a sheet of tracing paper, divided into 1-acre squares, drawn to the same scale as the plan with which it is to be used. The side of a square, of which the area is 1 acre, measures 316·228 links. The squares should be drawn in black lines, and sub-divided into quarter-acres by means of faint red lines. The area of coal wrought can be estimated with considerable accuracy by merely placing the sheet of tracing paper over the plan, and by counting the squares covering the space on the plan representing that area.

The area of the coal wrought and the thickness of the seam being known, the tonnage may be estimated approximately, as the specific gravity of the coal (1,250 to 1,500), with that of water taken as 1,000 for standard, is equal to the number of ounces in a cubic foot.

The produce of coal-seams depends not only upon the specific gravity of the coal (1·25 to 1·50), but also upon the system of working, and the number of faults. According to Professor J. H. Merivale, at a Durham colliery working the Harvey seam 3 feet 6 inches in thickness, 5,185 tons per acre were obtained when working by the long wall system, and 5,052 tons when working by the bord and pillar system. The yield per acre per foot thick of the South Staffordshire thick coal by the various methods of working is calculated by Mr. H. W. Hughes* to be as follows:—Square work, 1,243 tons; longwall (two divisions), 1,398 tons; longwall (one division), 1,155 tons.

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* *The Thick Coal of South Staffordshire,* Sheffield, 1885, p. 17.

A rough rule is to calculate the produce at 100 tons per inch per acre, which leaves an ample allowance of some 25 per cent. for loss of every kind. Another rule frequently used is to calculate the produce at 18 cwts. to the cubic yard. This gives $120\frac{5}{6}$ tons per inch per acre or 1,450 tons per foot per acre.

The Calculation of Ore-Reserves.—Having finished the survey of a metalliferous mine, the surveyor is sometimes called upon to calculate the quantity of ore-reserves in that mine. Various methods are employed for this purpose. Indeed different surveyors will not agree within wide limits as to the amount of ore-reserves in the same mine. Sometimes the amount of ore in sight will be considered to be a rectangular block limited by the outcrop of the vein, the depth of the shaft, and the extreme points of the levels, diminished by the amount extracted. Other surveyors would avoid so excessive an estimate and take but one-third of that amount.

The following method is recommended by Mr. J. G. Murphy, an experienced American mining-engineer, as the fairest and most trustworthy:—Let it be required to calculate the ore-reserves in a mine opened up on a vein with a mean cross-section of 6 feet; a cubic foot of the vein matter in place weighing 150 lbs. The ore stopes are generally very irregular. In this case, however, it may be supposed that the stope faces are 11 feet apart and 8 feet high. There is an inclined shaft, 10 feet by 6 feet, following the dip of the vein, and 6 levels, each 7 feet by 6 feet, 100 feet apart. The lengths of the levels are—

I.	200 feet west;	150 feet east.
II.	160 „	100 „
III.	120 „	400 „
IV.	100 „	140 „
V.	165 „	180 „
VI.	350 „	150 „

The longest level west is 350 feet and the shortest 100 feet. Assume the bounding line of the area of available ore to be at a distance west of the shaft,

$$100 + \frac{350 - 100}{2} = 225 \text{ ft.}$$

The longest level east is 400 feet, and the shortest 100 feet. The bounding line in this direction calculated in a similar way will be at a distance of 250 feet from the shaft.

The inclined shaft has opened up the vein for 670 feet. Deducting, say, 15 feet for the irregularity of the surface, the quantity of ore in sight will be a rectangular block 655 feet deep, 225 + 250 or 475 feet long, and 6 feet wide—that is, 1,866,750 cubic feet.

From this quantity, however, must be deducted the quantity of ore extracted, namely—

		Cubic Feet.
Inclined shaft,	655 × 10 × 6 =	39,300
Level I.,	350 × 7 × 6 =	14,700
Level II.,	260 × 7 × 6 =	10,920
Level III.,	520 × 7 × 6 =	21,840
Level IV.,	240 × 7 × 6 =	10,080
Level V.,	345 × 7 × 6 =	14,490
Level VI.,	500 × 7 × 6 =	21,000
Level I., stoped east (rough estimate),		3,400
Level I., stoped west, . . .		6,500
Level II., stoped west, . . .		7,000
Level III., stoped east, . . .		20,000
Level VI., stoped west, . . .		12,000
Total, ...		181,230
Or in round numbers, . . .		182,000

This quantity, deducted from 1,866,750 cubic feet, leaves 1,684,750 cubic feet. Divided by 13½, the number of cubic feet required for a ton (of 2,000 lbs.), this gives 124,797 tons of ore in sight.

The quantity of ore discovered in a mine may be estimated from its specific gravity and the average size of the vein. The specific gravity of the ore, with that of water taken at 1,000 for standard, is equal to the number of ounces in a cubic foot. Great caution is necessary to determine the proportion of the vein which may be considered solid ore.

A vein 6 feet square and 1 inch thick contains 3 cubic feet; therefore, in order to find the number of cubic feet per square fathom of a vein, it is merely necessary to multiply the thickness in inches by three.

The following example illustrates the method of finding the weight of any ore per square fathom in a vein :—What quantity of galena will be produced per square fathom from a mineral vein 6 inches in width? One-quarter of the vein consists of galena, the remainder of zinc-blende. One-twentieth must be allowed for cavities in the vein.

The specific gravity of galena is 7·5, and a cubic foot of water weighs 1,000 ounces; therefore, a cubic foot of galena weighs

7,500 ounces. The vein being 6 inches thick, there are 18 cubic feet in a square fathom. One-quarter of that amount, or 4·5 cubic feet, consists of galena. The weight of galena in ounces is therefore

$$7{,}500 \times 4{\cdot}5 = 33{,}750 = 2109{\cdot}375 \text{ lbs}$$

From this, one-twentieth, or 105·468 lbs., must be deducted, leaving 2003·907 lbs., or 17 cwts. 3 qrs. 15 lbs., as the weight of lead ore per square fathom.

For recording the value of ore-reserves, Mr. J. C. Little* points out that, on the vertical section of a mine, contour lines from level to level may be plotted exhibiting the number of units of value of ore existing, provided that sufficient details of lode width and assay values are available. Surface cost and general charges are usually expressed per unit of weight of ore milled; but by the aid of an ingenious slide-rule invented by Mr. Little, these costs can be distributed over the area worked, and the total cost per square inch recorded. In the Transvaal the stopes are surveyed every month; the surveys being sometimes plotted on the reef plane and the areas worked out computed with the planimeter. The calculation of ore reserves is exhaustively dealt with by Mr. A. G. Charleton.†

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* *Journal of the British Society of Mining Students*, vol. xx., 1897, p. 68.

† *Trans. Inst. Min. Met.*, vol. ix., 1901, p. 203.

CHAPTER XVI.

LEVELLING.

Definitions and Principles.—Levelling is the art of determining the relative distances of points from the centre of the earth. One point is said to be above another when it is farther from the centre of the earth, and the difference of distance from that centre is called the difference of level between the two points. The operation of finding how much one point is higher or lower than another may be trigonometrical, geometrical, or physical.

Trigonometrical levelling necessitates the measurement of lengths and angles. As an illustration, the simplest case may be taken. In order to determine the difference of level between A and C (Fig. 100), or in other words the line A B, the angle A C B, and one of the two lines A C and C B must be measured. The height required is then found by trigonometrical calculation from the two magnitudes measured.

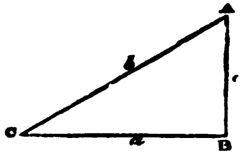

Fig. 100.

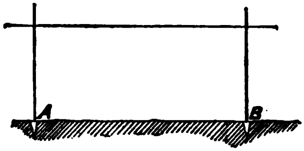

Fig. 101.

In geometrical levelling, a horizontal line or plane is constructed, and the distance of the two points A and B (Fig. 101) from this is measured directly by setting-up vertical staves. The difference of the two readings on the staves is the difference in level between the two points.

Physical levelling is based on the change of atmospheric pressure at different altitudes. The most important instrument for this method of levelling is the barometer.

The Spirit Level.—Instruments commonly used for levelling for surveying purposes comprise a spirit level and telescope as the essential features. The spirit level proper consists of a glass tube nearly filled with liquid, the interior form of the tube being shown in Fig. 102, the upper and lower curvatures, which are equal, being greatly exaggerated in the figure. The tubes from which the spirit levels are made are selected as truly cylindrical as possible as regards both their interior and exterior surfaces. The interior surface is then accurately ground lengthways to the form of a circular curve, the radius of which depends upon the class of instrument of which the spirit level is to form part. The larger the radius of curvature the greater the sensitiveness of the spirit level. The outer surface of the tube is graduated, and in accurate instruments the graduations correspond to a definite arc on the circular curve to which the interior surface has been ground. Thus, in the case of a dumpy level of average quality the divisions are not uncommonly one-tenth of an inch in length, and correspond to an arc of 30 seconds, the radius of curvature being about 60 feet. High-class levels are of considerably greater sensitiveness than this, and the same length of division may correspond to 10 seconds.

The tubes are usually filled with pure alcohol or a mixture of alcohol and ether. Pure ether is considerably more mobile than alcohol, and gives a much more active bubble. Chloroform gives a still more active bubble than ether. These two latter liquids are, however, rarely used alone for spirit levels for outdoor use, as owing to their low boiling points, there is a considerable risk of tubes of ordinary construction being burst on exposure to the sun, and apart from this the rapid change in the length of the bubble with varying temperatures is a source of trouble.

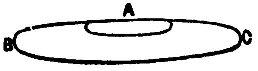

Fig. 102.

The glass tubes are mounted in metal tubes, which are attached to the levelling instrument by means of adjustable capstan-screws, and when the spirit level is in adjustment a radius drawn from the centre of curvature to the centre of the graduation on the tube is parallel to the vertical axis about which rotation of the telescope takes place.

The Dumpy Level.—The term spirit level is also applied to the levelling instrument, of which the spirit level proper is the essential part. The instrument most generally used in Great Britain is the *dumpy level,* invented by W Gravatt. It is represented in Fig. 104. A is the spirit level attached by screws at *a*, *a′*, to the telescope B C. A small spirit level is fixed transversely on the telescope, as shown at A′, and is used as a guide in setting up and for approximate levelling of the instrument. D is a flat bar or oblong plate fixed on the top of the vertical axis E. To this bar the telescope is attached by adjusting screws *d*, *d′*, which are also shown in section in Fig. 105. The vertical axis turns upon a hollow spindle fixed to the upper parallel plate F, the spindle being continued downwards and attached to the lower parallel plate G by a ball and socket joint. There are four levelling-screws *f*, by which the vertical axis is set truly vertical. The lower plate is screwed on the tripod head. The tripod consists of three wooden legs like those of the theodolite. In some instruments, a compass is carried on the top of the plate D for taking bearings of lines.

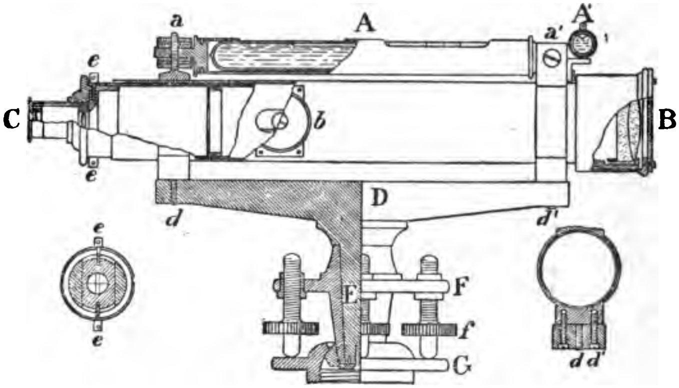

Fig. 103. Fig. 104. Fig. 105.

The telescope of the level is similar to that of the theodolite, except that the diaphragm contains one horizontal wire and two parallel vertical cross-wires, as shown in Fig. 106. The construction of the diaphragm itself is shown in Fig. 103. This levelling instrument derives its name from its dumpy appearance, due to the large aperture and short focal length of the telescope. The latter is usually 9 or 14 inches in length.

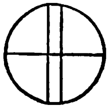

Fig. 106.

The Y-Level.—Of the different varieties of levelling instrument, that termed the Y-level is preferred by many engineers. In this instrument the telescope is mounted on Y's, like those of the Y-theodolite.

A form of American Y-level, made by Messrs. Heller & Brightly, of Philadelphia, is shown in Fig. 107 The telescope rests on

Y's, and is confined in them by clips fastened by binding-pins. The telescope is 17 to 20 inches long. It has at each end a ring of bell-metal; by these it revolves in the agate bearings of the Y's, and can be clamped in any position. The spirit level is attached to the under side of the telescope, and is provided at its ends with screws for horizontal and vertical adjustment. The level scale extends over the whole length, and is graduated into tenths of an inch. A clamp and tangent screw are connected with the axis for moving the bar and telescope.

Stanley's Engineers' Level.--The characteristic feature of this level is the casting of the telescope body in one piece with the centre, thus dispensing entirely with adjusting screws for the connection of the telescope. It is claimed that, notwithstanding its solid appearance, it is actually lighter than the older forms It is usually fitted with subtense points, a clamp and tangent screw being provided to assist in taking observations. The object end of the telescope tube is graduated, and slits are provided in the ray-shade for the purpose of taking cross levels.

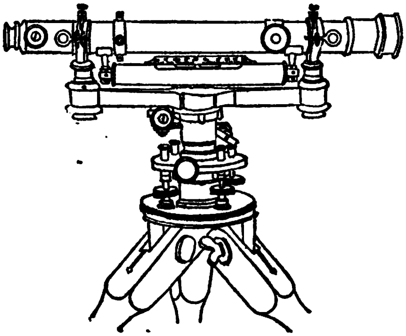

Fig. 107.

Cushing's Reversible Level.—On account of the inconvenience attending the adjustment for collimation in levelling instruments where the telescope is fixed, it occurred to Mr. Cushing,* Inspector of Scientific Instruments to the Indian Office, to make the eye-piece and object-glass of the telescope interchangeable. For this purpose he fixes to the internal tube of the telescope a gun-metal socket, which has a wide flange and is ground internally to a conical form to receive a fitting carrying the eye-piece and diaphragm. On the opposite end of the outer tube, a precisely similar socket receives the cell containing the object-glass. Both ends are identical as regards the fitting, though the object-end is necessarily rather longer than the eye-end on account of its having to carry on the outside the cover or dew-cap. The line of collimation is adjusted by reversing the collimation stop, which in this level is a glass disc with lines engraved upon it by a fine diamond, instead of the ordinary cross-wires.

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* *Min. Proc. Inst. C.E.*, vol. lix., 1880, p. 278.

Zeiss Level.—The firm of Carl Zeiss, Limited, have within the last few years put on the market several new types of level, of an entirely different construction from those previously described. Two very striking features are, a prismatic arrangement to enable the observer to see the bubble whilst he is sighting the staff and an arrangement for moving the telescope through a limited angle in a vertical plane with a view to bringing the bubble to its central position at the moment of sighting. The telescope can also be rotated through 180, in its supporting collars, being similar to the Y level in this respect, except that the telescope can be rotated completely in the latter. The eye-piece can also be used at either end of the telescope tube, and these two last provisions enable four observations to be made, either for obtaining the greatest precision possible or for adjusting the instrument.*

In this and other countries much attention has been paid in recent years to the manufacture of precise levels, and great improvements have been effected. Most makers supply some form of reflecting device to enable the operator to view the bubble whilst sighting the staff, any necessary correction being made with one of the levelling screws, although the limited movement of the telescope in a vertical plane, controlled by a special operating screw, is provided for by several makers other than the firm mentioned above. As in the case of the theodolite, the adoption of three levelling screws instead of four is rapidly increasing, and the tribrach form is now standard with most makers.

Temporary Adjustments of the Level.—The function of a level being mainly to establish a horizontal line, it is not generally necessary to set the level over any definite point, so that the operation of centring is not required.

The levelling up of the instrument is carried out in much the same way as the theodolite, attention being paid to both the main telescope bubble and to the small transverse level when setting the tripod.

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* See paper by Mr. Joseph Husband on "The Zeiss Level," *Trans. Inst. of Min. Eng.*, vol. xlvi., p. 285.

The telescope is brought into line with one pair of screws and the main bubble centred, then the bubble of the small transverse spirit-level is centred by the other pair of screws, or single screw in the case of tribrach instruments, the main bubble is now re-adjusted and then brought to a position at right angles to its former position and the bubble again centred. It is then again recentred in its first position, and as a rule if in adjustment will now permit of a complete revolution of the telescope being made without the bubble moving.

The adjustment for parallax is made in the same way as with the theodolite, but as a rule it is made when sighting the staff itself for the first observation, and the eye is moved up and down instead of across the eye-piece whilst testing the adjustment.

When sighting the staff the latter should always be viewed between the vertical cross-wires, so that its verticality may be ensured. The reading of the staff is taken with the central horizontal cross-wire. It is usually necessary to re-focus the staff for each sight to enable the readings to be taken with the necessary degree of precision.

Permanent Adjustments of the Dumpy Level.—In the case of the dumpy level, the two essential conditions that should be fulfilled are the following :—The main telescope spirit level should be at right angles to the vertical axis, and the line of collimation should be parallel with the spirit level, and consequently also at right angles to the vertical axis.

The adjustment of the spirit level at right angles to the vertical axis is tested every time the instrument is carefully levelled in the usual way with the foot-screws. If the telescope cannot be turned through a complete revolution without appreciable movement of the bubble, the adjustment is not correct. In order to make the adjustment the telescope is turned in line with one pair of the foot-screws, and the bubble accurately centred by means of the latter, the telescope is then turned through 180°, and the amount and direction of the deviation of the bubble from the centre is noted; this represents twice the error in the adjustment, which is corrected by eliminating half the deviation by means of the capstan screws provided at one end of the spirit level. To test the adjustment, eliminate the other half of the deviation by means of the foot-screws, turn the telescope through 90° to bring it in line with the other pairs of foot-screws, and, using the latter only, centralise the bubble. It should now be possible to turn the telescope through a complete revolution without appreciable movement of the bubble.

To test the adjustment of the line of collimation advantage is taken of the fact that the true difference of level between points equidistant from a levelling instrument can be determined, independently of any adjustments or corrections, provided the instrument is in good mechanical order. To make the test the instrument is set up on a piece of ground extending as nearly level as possible for a distance of 4 or 5 chains. From the centre of the instrument a distance of a chain is set out on either side and pegs driven in. The points should be so chosen that the two pegs and the centre of the instrument are in line. After carefully levelling the instrument, the reading of a levelling staff held on either peg in turn is taken, the bubble being brought very exactly to the centre of its run immediately before taking the reading in each case. The peg at the higher level is driven into the ground until the reading of the staff is the same as at the other peg. The two pegs are then at exactly the same level. This will be evident from Fig. 110 and the considerations put forward on p. 270.

The testing of the line of collimation can now be effected by setting the instrument up at a point outside the two pegs. For convenience it is advisable to make the distance between the two positions of the instrument exactly 2 chains, and still in line with the pegs, the latter, however, being both on the same side of the instrument in the second position. The instrument is carefully levelled, and a reading is taken with the staff held on either peg, the bubble being centred for each observation as before. The two readings should be identical if the adjustment of the line of collimation is correct. If the readings are not the same, the difference between them represents the effect of the error of collimation for the distance *between the pegs*.

In order to correct the adjustment, assuming that the distances have been set out as described, the following procedure is adopted:—Ascertain the difference between the last two readings and note whether the reading taken at the peg nearest the instrument is the greater or lesser of the two. If greater add to it one-half of the difference between the readings, if less deduct this amount from it, the result in either case gives the reading that would have been obtained if the adjustment for collimation had been correct. The staff is then set up on either peg and the collimating screws attached to the diaphragm are manipulated until the correct reading is given by the cross-wires.

It is advisable to make the adjustment of the spirit level at right angles to the vertical axis before making that for the line of collimation.

Adjustments of the Y-Level.—The temporary adjustments are identical with those for the dumpy level, the permanent adjustments, however, are somewhat different, and, as a matter of fact, can be more easily and correctly made; on the other hand, they are much more liable to disturbance. The adjustments required are as follows:—First to set the spirit level parallel with the axis of the telescope, second to make the line of collimation coincide with the axis of the telescope, and third to set the axis of the telescope at right angles to the vertical axis.

To test the parallelism of the spirit level and the telescope axis the instrument is set up and levelled carefully with the foot-screws, finishing up with the telescope in line with a pair of the latter. When the bubble is accurately centred, the Y's are opened and the telescope reversed end for end. If the bubble comes to rest in the centre of its run this adjustment is correct. If it does not, the deviation of the bubble represents twice the error, which is corrected by eliminating half the deviation by means of the capstan-screws attached to the spirit level. The correction of the adjustment can be tested by eliminating the remaining deviation of the bubble by means of the foot-screws and again reversing the telescope end for end in the Y's, the bubble should come to rest in the centre of its run.

To test the coincidence of the line of collimation with the axis of the telescope, having, if necessary, corrected the first adjustment, an observation is taken on to a levelling-staff held vertically at a point at about 3 chains away from the instrument. Having taken the reading of the cross-wire on the staff, the telescope is rotated in the Y's through 180°, and the staff reading again taken. If the readings are identical the adjustment for collimation is correct; if they differ, the difference between them represents twice the error of collimation for the distance of the staff from the instrument. The correction is made by manipulating the collimating screws attached to the diaphragm until the cross-wire gives the mean of the two previous readings. On again rotating the telescope through 180° in the Y's, the reading should remain the same.

To test the adjustment of the axis of the telescope at right angles to the vertical axis, the first adjustment being correct, the telescope is brought into line with a pair of foot-screws and the bubble centred accurately. The telescope is then rotated about the vertical axis through half a revolution. If the bubble remains central, the adjustment is correct; if it does not, the deviation represents twice the error in the adjustment, which is corrected by eliminating half the deviation, by means of the screws which form the attachment of the Y's to the plate. The correction of the adjustment is tested by eliminating the remaining deviation of the bubble from the centre of its run, by means of the foot-screws, and rotating the telescope back to its former position, when the bubble should remain central.

The Levelling-staff serves to measure the vertical distance from the horizontal line formed by the axis of the telescope down to the station on the ground. Formerly the levelling-staff consisted of a wooden rod, furnished with a sliding vane or target, which was raised or lowered by the staff-holder in response to signals from the observer. Such staves are now rarely used. The principal objection to which they are liable is that the observer must depend on the staff-holder to read the height observed, or if the latter is not sufficiently intelligent to perform so important a duty, must himself go and read off the height of the vane. In this way great loss of time is caused, and there is uncertainty in the results, as the vane may possibly have shifted in the meantime.

A very perfect staff of this kind, known as the New York target rod, is largely used in the United States. It is graduated to hundredths of a foot. To indicate where the horizontal line cuts the staff, a target is used, the face of which is divided into quadrants painted with two alternate colours. In the face, there is an opening a tenth of a foot long, through which the figures can be seen on the face of the rod. The right edge of the opening is provided with a vernier, by means of which the staff can be read to thousandths of a foot.

In order to avoid entrusting the reading of the staff to an attendant, Mr. W. Gravatt invented a staff, the face of which was graduated distinctly enough for the observer himself to read off the figures through the telescope of his instrument. The sliding vane is thus dispensed with, and the staff-holder has nothing to do but to hold the staff vertical.

The levelling-staff usually consists of three parts, sliding one within the other, and, when opened out for use, forms a staff 14 to 16 feet in length. It is made of mahogany soaked in boiled oil, and painted with several coats of oil paint. The whole length is divided into hundredths of a foot, coloured alternately black and white, and occupying half the breadth of the staff. The patterns of levelling-staves are very various. The form shown in Fig. 108, invented by T. Sopwith, F.R.S., is that most frequently used. In this the feet are represented by large red figures, the tenths are shown by odd black figures, and the hundredths are coloured alternately black and white. Between the odd figures representing tenths, a black diamond is painted to indicate the alternate five-hundredths. The top of every figure represents its value. Of the black and white divisions, the bottom of each black space represents odd hundredths, the top even hundredths. The staff is usually 14 feet in length, and divided into three parts, which, when drawn out, are held in position by a spring clip at the back. When closed, they form a staff about 5 feet 3 inches in length, 3 inches wide, and 1½ inches deep.

An important modification has been introduced in the graduation by Mr. A. G. Thornton, of Manchester. It consists in the repetition at each 3 inches of the number of feet in small red figures on the left of the staff. This improvement will be found very advantageous, especially with short lines of sight, as an exact reading can be taken on any part of the staff where the cross-wire falls, without the necessity of raising or lowering the staff. It is important that the staff be held truly vertical while it is being read. To help the staff-holder in this, a small plummet is suspended in a groove cut in the side of the staff, by means of which its verticality can be determined in one direction. The observer himself can detect by means of the two vertical wires of the telescope whether it inclines in the other direction. The plummet may be replaced by a round spirit level, the tangential plane of which is perpendicular to the back of the staff.

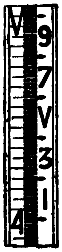

Fig. 108.

The error caused by the staff being inclined is considerable. Let h be the reading on the staff when it is held vertical, and h' the reading when the staff is inclined at an angle of δ from the vertical. Then $\frac{h}{h'} = \cos \delta$, and $h' = \frac{h}{\cos \delta}$. Thus, if $\delta = 2°$, and $h = 4$ feet, then $h' = 4{\cdot}002$ feet.

If necessity should compel the staff to be used without a plummet or round spirit level, it should be moved backwards and forwards by the staff-holder; the lowest reading is taken as the most correct one, although this is not strictly true in all cases.

A triangular piece of sheet iron, about one-tenth of an inch in thickness, having the corners turned down, is used to rest the staff on. The corners are pressed into the ground. By means of this iron plate, the staff is kept on the same spot, and at the same height from the ground, while the observer is reading the back- and fore-sight. A chain and ring are attached to the plate for the convenience of the staff-holder in lifting it from the ground, and in carrying it from station to station.

Mine Levelling-Staves.—For levelling underground, staves may be employed similar in construction to those used at the surface. They must, of course, be shorter. The best sizes are a 9-foot Sopwith staff to close down to 3 feet 6 inches, or a 6-foot Sopwith staff to close down to 2 feet 6 inches. The staff is illuminated by means of a miner's candle or a safety-lamp. Mr. Stanley has designed a staff, made in lengths of 18 inches, like a folding rule.

Mr. G. J. Jee* has designed a useful staff for colliery work. It consists of three lengths, sliding one into the other. The bottom length is graduated upwards in the ordinary way, and is 3 feet in length. At the top of the first division of the staff is attached a 2-inch band, which is graduated upwards, and forms an accurate continuation of the scale on the lower division of the staff. The band passes over a brass roller attached to the top division of the staff, and thence is carried down and wound round a brass drum, fixed just below the roller, to the top of the same length of the staff, the band being kept in tension by means of a spring-box attached on one side to the axis of the cylinder. It is thus evident that when the second length of the staff is drawn out, the band unwinds and gives a continuous reading up to 5 feet 8 inches, or to any intermediate distance that the height of the roof will allow. In the same way when the third length is drawn out, a continuous reading may be obtained up to 9 feet, or to any intermediate distance required. The weight of the staff is 5 lbs. It is manufactured by Messrs. J. Davis & Son, of Derby.

The clumsy contrivances used in the St. Gothard tunnel induced Professor M. Schmidt,† of the Freiberg School of Mines, to devise a staff specially adapted for levelling in mines. It consists of two staves, each 5 feet in length. The front one is graduated, whilst the second acts as a pedestal. The two are joined together by two clamps and screws, in such a way that the graduated staff may slide along the pedestal for a distance of

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* *Colliery Guardian*, vol. xxxviii., p. 576, 1879.

† *Oesterr. Zeitschr.*, vol. xxix., p. 295, 1881.

4 feet. The graduated staff is backed with an iron plate drilled with small holes, corresponding to its graduation. Into these a steel pin on the pedestal works automatically with a spring, whenever the graduated staff is drawn in or out. A pointer is attached to the pedestal at a given height (*e.g.*, 4 feet), when the graduated staff is pushed home. When the latter is drawn out, the reading, less the difference between the foot and the pointer, added to the constant height, denotes the height of the line of sight above the foot of the staff.

Attached to the side of the staff is a portable reflector lamp for illuminating the scale. It can be raised or lowered at will, and its reflector is so placed that as much light as possible falls upon the scale, whilst the flame itself is kept out of sight. In mines where the ground is stony or soft, a cast-iron shoe with a hemispherical steel head is placed under the staff.

For very accurate levelling, Borchers' vane-rod is generally used in the Continental mines. To enable this contrivance to be used, all the station-points must be marked by small hooks fixed into the roof of the underground road. The contrivance consists of a steel rod, rectangular in section, 5 feet 5 inches in length, provided at its upper end with a movable hook. The rod is graduated into inches, the graduation proceeding from the inside of the hook to the lower end of the rod. Up and down the rod slides a sheet-iron circular vane or target, 8 inches in diameter, which may be clamped at any height. At right angles to the longitudinal axis of the rod, a line is scratched through the centre of the vane. With their centres truly on this line, three circular apertures are cut, two 0·4 inch in diameter, and one 0·07 inch in diameter. In front of one of the larger openings a piece of ground glass is fastened. To the back of the vane a vernier is fastened with its zero coinciding with the horizontal line scratched on the vane.

In levelling, the rod is hung from a hook in the roof of the mine-road, and the vane placed at right angles to the line of sight. For very short station-lines, the flame of a miner's lamp is held behind the small hole, and the vane moved up or down until the horizontal cross-wire of the telescope coincides with the point of light sighted. For greater distances of 60 to 200 yards, the aperture covered with ground glass is used if the air is clear; with still greater distances the uncovered aperture is used. Very long station-lines are not to be recommended, on account of the difficulty of communicating with the assistant.

This levelling-rod is exceedingly simple. It hangs perpendicularly by its own weight, and, unlike wooden staves, it is not affected by the water and dirt in the mine. At the same time it presents the advantages of fine adjustment, exact reading, and great rapidity.

Practice of Levelling.—If it is required to determine the difference of level between two points not very far apart, this may be done by *simple levelling*. For this purpose, the levelling-instrument is set up midway between the two stations A and B, Fig. 109. With the bubble remaining unmoved in the middle of its tube, the telescope is directed towards a staff held vertically at A, and the reading h noted. The staff is then held vertically at B, and the telescope directed towards it, the reading h' being noted. The difference of level between the two points A and B is then $h - h'$, and B is higher than A when h is greater than h'. The difference of level is thus determined by two readings on the staff, one with the telescope directed backwards towards the staff at A, and the other with the telescope directed forwards to the staff at B, or, in other words, by means of a *back-sight* and a *fore-sight*.

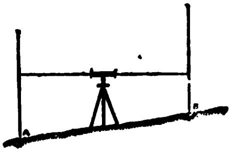


Fig. 109.

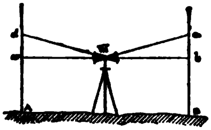


Fig. 110.

In order to obtain the greatest accuracy, the instrument is set up as nearly as possible midway between the two stations A and B. The advantage of thus placing the instrument is that the instrumental errors and the errors due to the curvature of the earth and to refraction are neutralised.

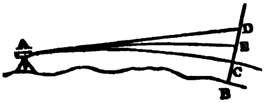


Fig. 111.

Let the instrument be set up at m, Fig. 110, so that $m\,a = m\,b$, and let $a\,b$ be a horizontal line. Then if all the sources of error act in such a way that the optical axis of the telescope directed towards the staff at A gives an angle, $a\,m\,d$, with the horizontal line, the cross-wires of the telescope will not coincide with the point a, but with the point d, and on directing the telescope to the staff at B, the cross-wires will coincide not with point b. but with c. The same causes being at work in both positions of the telescope, the angles $a\,m\,d$ and $b\,m\,c$ must be equal. Because $m\,a = m\,b$, $a\,d = b\,c$. The difference in level is equal to $h - h'$ —that is, $(\mathrm{A}\,a + a\,d) - (\mathrm{B}\,b + b\,c)$. It is here assumed that the condition of the atmosphere is the same with the fore-sight as with the back-sight, and thus the refraction is the same in both cases.

The influence of the curvature of the earth's surface is dependent on the radius of the earth, r, and on the distance l between the instrument and the staff. Imagine an arc of a circle to be described passing through the telescope axis A, Fig. 111, and with the centre of the earth as centre. The arc will intersect the staff set up at B in the point C. The curvature in the figure is, of course, very much exaggerated. The horizontal line passing through A, intersects the staff at the point D. Thus, A C is the true horizontal line, A D the apparent horizontal line, and C D the depression of the true below the apparent horizontal line. Then the correction for curvature is — C D, a third proportional to the earth's diameter and distance between the level and the staff. C D is thus equal to $\frac{l^2}{2r}$. For a distance of 1 mile this correction is 8 inches, or two-thirds of a foot. Two-thirds of the square of the distance in miles will be the amount of the correction in feet.

The error C D is diminished by the refracting action of the air which results in the real line of sight being curved. The curve being concave downwards, the point D is not seen at the cross-wires of the telescope, but the point E. With a calm clear atmosphere, D E is equal to 0·1348 C D, or $0{\cdot}1348\,\frac{l^2}{2r}$. The coefficient 0·1348 is the mean of the determinations of several physicists.

The total error due to the curvature of the earth and to refraction is thus $\frac{l^2}{2r} - 0{\cdot}1348\,\frac{l^2}{2r} = \frac{0{\cdot}4326\,l^2}{r}$. The earth's diameter being equal to 41,778,000 feet, the correction for curvature and refraction per mile would be

$$0{\cdot}4326 \times 5280^2 \div 20{,}889{,}000 = 0{\cdot}577 \text{ foot} = 6{\cdot}92 \text{ inches.}$$

At distances up to 10 chains, the errors produced by curvature and refraction are so small that they may be neglected.

In crossing over a deep valley it is sometimes necessary to set up the level at one of the points A and the staff at the other point B, in which case the height of the centre of the instrument above the ground must be measured. The difference of level d will then be equal to the height of the instrument i above the ground, less the reading on the staff h—that is, $d = i - h$. If the correction c for curvature and refraction has to be taken into account the formula becomes

$$d = i - (h - c) = i - h + c.$$

If the instrument is placed at B, and the staff at A, the difference of level is

$$d = h' - c - i'.$$

The mean of these two values gives the difference of level independently of all correction—

$$d = \frac{h' - h}{2} + \frac{i - i'}{2}.$$

When the distance is too great or the ground too much inclined for the difference of level to be determined by one operation, recourse must be had to *compound levelling*, a process consisting of several simple levelling operations. The difference of level of each two successive points is determined in the way described. Fig. 112 gives an example of compound levelling. By setting up the levelling-instrument at the three stations, the following values were obtained:—

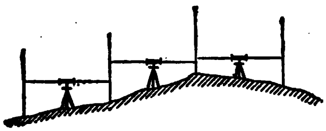


Fig. 112.

	Back-Sight Feet.	Fore-Sight Feet.		Feet.
I.	A D = 6·71	B E = 3·92	Rise from A to B =	2·79
II.	C F = 7·86	C G = 2·41	Rise from B to C =	5·45
III.	H C = 2·84	D I = 6·39	Fall from C to D =	3·55
	17·41	12·72	Rise =	4·69

If the back-sight is greater than the fore-sight, the ground rises. If the fore-sight is greater than the back-sight, the ground falls. The rises being regarded as positive, and the falls as negative, the algebraical sum gives as the result of the levelling that D is 4·69 feet higher than A. The same result is obtained when the sums of the back-sights and of the fore-sights are taken, and the smaller sum subtracted from the larger. Thus $17{\cdot}41 - 12{\cdot}72 = 4{\cdot}69$. The difference obtained is difference in level between the end points. It indicates a rise when the sum of the back-sights is the greater, and a fall when that of the fore-sights is the greater.

This is the method of conducting a *flying-level*—that is, a levelling operation merely to determine how much one point is above or below another. If, for example, it is required to determine what thickness of strata there is, at a certain point A at the surface, above the present workings in the mine below it, the depth of the shaft is measured, and levelling commenced at the bottom of the shaft and continued to the point underground directly below A. A flying-level is then made at the surface from the shaft to A. The depth of the shaft being known, the thickness of the strata at A can be calculated from the rise or fall determined at the surface and underground. Thus, if the shaft is 300 feet deep, and the point underground is found to be 5 feet lower than the bottom of the shaft, whilst the point A at the surface is found to be 40 feet higher than the top of the shaft, the thickness of the strata at A will be $300 + 5 + 40 = 345$ feet.

Section-levelling.—When a section of the ground is to be drawn, the distance between the several stations must be carefully measured. The levelling-instrument should be placed as near as possible midway between the two stations, and the levelling is then conducted in the manner described. To facilitate the plotting of the section, the levels of the various points are calculated with reference to an assumed level-line called the *datum-line*, such calculated levels being called *reduced-levels*. In order to avoid complication, it is advisable to choose such a datum-line that the levels of all the points concerned in making the section are *above* the datum-line.

The observations are recorded in the levelling-book in the manner shown in the table on p. 274.

The starting-point is 50 feet above the datum-line, which in this case was the level of the high-water mark at London Bridge. The figures in the "Rise" and "Fall" columns are obtained by taking the difference between the back-sights and fore-sights. Reduced levels are obtained progressively by adding or subtracting the rise or fall to or from the reduced level of the back-sight, bearing in mind that the point at which the fore-sight for one setting is taken is the same as that at which the back-sight for the succeeding setting is obtained. Thus, for setting E, the reduced level of the back-sight having been ascertained to be 60·18, that of the fore-sight is equal to $60{\cdot}18 - 5{\cdot}09 = 55{\cdot}09$.

FORM OF RECORD I.

No.	Back-sight.	Fore-sight.	Rise.	Fall.	Reduced Levels.	Distance. Chains.	Remarks.
A	5·49	0·06	5·43	..	55·43	1·50	Back-sight is 50·00 ft. above datum.
B	4·32	2·24	2·08	..	57·51	4·70	
C	8·40	1·52	6·88	..	64·39	9·12	
D	3·21	7·42	..	4·21	60·18	10·36	
E	1·41	6·50	..	5·09	55·09	13·96	
F	1·68	4·53	..	2·85	52·24	16·38	
G	7·20	0·22	6·98	..	59·22	19·98	
H	12·60	9·51	3·09	..	62·31	24·98	
J	9·51	0·33	9·18	..	71·49	29·18	
K	5·02	4·18	0·84	..	72·33	32·78	
L	5·08	4·02	1·06	..	73·39	36·36	
M	6·01	3·07	2·94	..	76·33	40·68	
N	6·82	4·00	2·82	..	79·15	45·73	
..	76·75 47·60	47·60	41·30 12·15	12·15	79·15 50·00	..	
	29·15		29·15		29·15		

As a test of the accuracy of the arithmetical work, the columns of back- and fore-sights should be added up, and the smaller sum subtracted from the larger. The result should agree with the calculated height above datum. Another test is afforded by adding up the rise and fall columns, when, if upon subtracting the smaller sum from the greater, the remainder is the same as that obtained by the two other operations, there can be no doubt that the levels have been correctly calculated. Thus, in the example given, the height of N above the starting-point is 79·15 − 50·00 = 29·15 feet. The sum of the back-sights being 76·75, and that of the fore-sights 47·60, the difference also gives 29·15 feet as the height of N above the starting-point. Lastly, the sum of the rises is 41·30, and that of the falls 12·15, the difference being 29·15 feet as before.

In order to make a correct section of a continuous surface, the levels of a series of points may be determined with the instrument at one station. The first and last observations are then the principal back- and fore-sights respectively. Thus, in Fig. 113, A is a station where the instrument is set up, and *b* A *c* is the line of sight. The first back-sight is taken with the staff at the starting-point B, of which the height above the datum-line is known. The reading on the staff is B *b*, or 2·95 feet. Between the points B and C, several intermediate sights are taken. The first intermediate sight, taken with the staff at the point marked 1, is at the same time a fore-sight to B, and a back-sight to the point marked 2; 3 is a fore-sight to 2 and a back-sight to 4, and so on with the other points. The final fore-sight for the first setting of the instrument is taken with the staff at C, giving the reading C *c*, or 0·58 foot. When the level is carried on to a new station D, the assistant holds the staff at C, at exactly the same point as it was for the fore-sight from A. The first back-sight C *c′* or 8·20 feet is taken, and the process repeated until the fore-sight E *e*, or 1·01 foot, is taken.

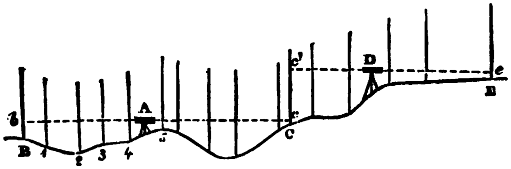


Fig. 113.

The readings are recorded and reduced in the manner shown in the following table:—

FORM OF RECORD II.

No.	Back-sight.	Fore-sight.	Rise.	Fall.	Reduced Levels.	Distance. Links.	Remarks.
1	2·95	3·99	..	1·04	98·96	35	First back-sight is 100 feet above datum.
2	3·99	4·90	..	0·91	98·05	90	
3	4·90	3·99	0·91	..	98·96	125	
4	3·99	3·08	0·91	..	99·87	165	
5	3·08	1·07	2·01	..	101·88	220	
6	1·07	1·88	..	0·81	101·07	245	
7	1·88	5·00	..	3·12	97·95	295	
8	5·00	5·52	..	0·52	97·43	335	
9	5·52	1·23	4·29	..	101·72	400	
10	1·23	0·58	0·65	..	102·37	420	
11	8·20	7·30	0·90	..	103·27	455	
12	7·30	6·50	0·80	..	104·07	515	
13	6·50	2·08	4·42	..	108·49	580	
14	2·08	1·81	0·27	..	108·76	635	
15	1·81	1·01	0·80	..	109·56	740	
..	59·50 49·94	49·94	15·96 6·40	6·40	109·56 100·00	..	
..	9·56	..	9·56	..	9·56	..	

The first back-sight and last fore-sight of each line of sight are the most important in point of accuracy. Any error made in taking an intermediate sight affects the point at which it was taken only, whilst any error in the back-sight or fore-sight is carried on throughout the section. In order to correct for curvature and refraction, the first back-sight and last fore-sight of each line should be at points as nearly as practicable equidistant from the instrument.

In recording the readings in the levelling-book, a separate column may with advantage be used for the intermediate sights. The readings are reduced, and the computations checked in the manner shown in the following table:—

FORM OF RECORD III.

No.	Back-sight.	Inter-mediate.	Fore-sight.	Rise.	Fall.	Reduced Levels.	Total Distances.
						Feet.	Links.
1	2·95	..	..	..	..	100·00	0
2	..	3·99	..	..	1·04	98·96	35
3	..	4·90	..	..	0·91	98·05	90
4	..	3·99	..	0·91	..	98·96	125
5	..	3·08	..	0·91	..	99·87	165
6	..	1·07	..	2·01	..	101·88	220
7	..	1·88	..	..	0·81	101·07	245
8	..	5·00	..	..	3·12	97·95	295
9	..	5·52	..	..	0·52	97·43	335
10	..	1·23	..	4·29	..	101·72	400
11	8·20	..	0·58	0·65	..	102·37	420
12	..	7·30	..	0·90	..	103·27	455
13	..	6·50	..	0·80	..	104·07	515
14	..	2·08	..	4·42	..	108·49	580
15	..	1·81	..	0·27	..	108·76	635
16	..	..	1·01	0·80	..	109·56	740
..	11·15	..	1·59	15·96	6·40	109·56	..
	1·59	..		6·40		100·00	
..	9·56			9·56		9·56	..

There is a second method, known as the collimation method, of reducing levels. It saves one column of figures, and is easier to work out, as the distinction between rises and falls is not considered. The following is the form of record:—

FORM OF RECORD IV.

Back-sights.	Inter-mediate.	Fore-sights.	Reduced Level of Collimation.	Reduced Levels.	Total Distances.
				Feet.	Chains.
0·15	..	..	206·04	205·89	0·00
..	4·80	..	..	201·24	1·00
..	3·80	..	..	202·24	2·00
5·49	..	8·00	203·53	198·04	3·00
..	5·44	..	..	198·09	4·00
..	9·25	..	..	194·28	5·00
..	..	9·64	..	193·89	6·00
5·64	..	17·64	..	205·89	..
		5·64		193·89	
		12·00		12·00	

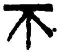
In the column headed "reduced levels of collimation" the figures are obtained by adding the back-sight reading to the reduced level of the point on the ground at which the back-sight was taken. The reduced levels of the remaining points on the ground are obtained by subtracting each of the staff-readings, whether intermediate or fore-sight, from the corresponding reduced collimation-levels. Thus, in the record given, the first reduced collimation-level is obtained by adding 0·15 to 205·89, which gives 206·04, and from this are subtracted each of the readings 4·80, 3·80, and 8·00. The second reduced collimation-level is obtained by adding the back-sight reading 5·49 to the reduced level 198·04.

Should it be required to work out the levels backwards, the rule is:—Add the fore-sight readings to the reduced level of the corresponding ground point at which they were taken, in order to obtain the reduced levels of collimation, and then subtract the corresponding intermediate and back-sight readings.

On reaching the bottom of a page in the levelling-book, if there is no necessity to move the instrument, the last intermediate sight is booked as a fore-sight at the bottom of the page, and again as a back-sight at the top of the following page. By so doing, the same number is added to, and subtracted from the collimation height, and consequently the reduced heights are not affected. The accuracy of the calculations is ascertained in the ordinary way, by adding all the back-sights and all the fore-sights, and subtracting the smaller total from the larger one. It must be borne in mind, however, that in the collimation method of calculation no arithmetical check on the calculation of the reduced levels of the intermediate sights is obtained.

A modification of this form of booking will be found advantageous for levelling in mines. Only two columns are used for entering the heights observed on the staff. The intermediate and fore-sights are placed in one column, the latter being distinguished by being underlined.

The advantages of this method, especially for underground levelling, are apparent, as it necessitates the writing of fewer figures. The form of record for this system, recommended by Mr. H. W. Hughes, is shown by the extract from his levelling-book of a South Staffordshire colliery. (Record V.)

Bench Marks.—When a section has been completed, it is generally necessary to check its accuracy by repetition. To do this, it is advisable in levelling to follow the shortest route, and to level at intervals to some known points on the line of section. The points thus selected are usually *bench marks.* These are fixed points of reference, the levels of which are known. In the Ordnance Survey of Great Britain, the bench marks are generally chiselled on some permanent stone slab, pillar, or wall. The form of mark for them is the broad arrow . In levelling on long lines of section, a bench mark is generally made at about every quarter of a mile, so that any error in the operation may not involve re-levelling the whole line. By referring to the maps of the Ordnance Survey, the heights may be found of the bench marks above the datum-line (the level of mean tide at Liverpool).

In collieries it is the general practice to record the levels of the works from some fixed datum near the shaft, as, for example, the flat sheets at the top or bottom of the shaft, the delivery of water from the high set of pumps, or some other fixed point. Mr. J. A. Ramsay* proposes to take or continue the Ordnance levels into the workings. In the Ordnance bench mark the broad arrow points upwards to a horizontal line. To make a distinction, it is suggested that as soon as the levels become lower than the datum-line or sea-level, the broad arrow should be reversed. The levels obtained in this way may be written upon the plan in plain figures at particular points on the main roads, and, when necessary, may be continued into the face of the workings.

Mr. Ramsay gives the accompanying extract from his levelling-book to illustrate the method he proposes of continuing the Ordnance levels into the workings of a colliery. (Record VI.)

* *Trans. N. Eng. Inst. M.E.*, vol. xx., 1870, p. 73.

FORM OF RECORD V.

Back-sight.	Fore and Inter-mediate Sights.	Reduced Levels.	Distance.	Remarks.
			Feet.	
0·70	..	102·72	5,466	Datum 100 feet below inset, distance measured from pit shaft. Section of seam.—Coal, 3′ 9″; dirt, 0′ 5″; coal, 3′ 2″; floor composed of clay.
	2·98	100·44	5,500	floor of coal.
	5·74	97·68	5,544	3″ up coal.
0·13				
	5·08	92·73	5,600	floor of coal.
0·13				
	6·37	86·49	5,671	,, ,,
0·88				
	2·94	84·43	5,700	,, ,,
	5·35	82·02	5,761	3″ up coal.
4·55				
	4·96	81·61	5,800	5″ below coal.
	3·75	82·82	5,823	floor of coal.
4·00				foot of fault, rise about 9 yards, fault hades 15°.
	4·30	82·52	5,900	
	0·18	86·64	5,966	
5·18				
	0·30	91·52	6,015	crossing measures below coal.
4·50				
	0·16	95·86	6,048	
5·29				
	0·05	101·10	6,078	
3·80				
	0·01	104·89	6,111	
6·58				
	0·01	111·46	6,136	
4·15				
	4·50	111·11	6,251	floor of seam.
	2·35	113·26	6,348	1′ 0″ above bottom of coal.
	2·75	112·86	6,402	0′ 6″ ,, ,,
4·48				
	4·46	112·88	6,517	floor of seam, road to left.
	3·64	113·70	6,623	2″ above bottom of coal.
3·93				
	3·11	114·52	6,781	floor of coal.
	4·08	113·55	6,803	,, ,,
	5·15	112·48	6,921	,, ,,
	5·30	112·33	7,017	3″ below coal.

Proof.—Total fore-sights = 38·69; total back-sights = 48·30. Difference (viz., rise) = 9·61, which, added to 102·72, the reduced height at 5,466, gives 112·33, the reduced height at 7,017.

FORM OF RECORD VI.

No.	Back-sight.	Fore-sight.	Rise.	Fall.	Datum.	Distance.	Remarks.
					85·90	..	Ordnance B.M. on north-east corner of watch house.
1	3·31	5·08	..	1·77	84·13	..	..
2	4·02	11·00	..	6·98	77·15	..	..
3	2·60	4·40	..	1·80	75·35	..	The flat sheets on lip of pit.
							Take Depth of the Pit with 100 feet Chain.
							Depth, 518 ft. 11 in.=518·91. Less surface height above datum.
	..	..	..	518·91	443·56	..	Flat sheets at bottom of pit; reversed Ordnance B.M. cut into stone walling, side of pit.
							Level down Cross-cut to make Section for Engine Plant.
1	6·85	5·94	0·91	..	442·65	90	7·9 ft. high—Hard post cover.
2	5·94	5·19	0·75	..	441·90	129	7·5 „ „
3	5·19	5·04	0·15	..	441·75	165	8·0 „ „
4	5·04	3·29	1·75	..	440·00	210	6·0 „ —Blue metal cover.
5	3·75	5·05	..	1·30	441·30	276	5·3 „ „ (timbered).
6	2·53	5·54	..	3·01	444·31	354	On the brow of large down-throw trouble, measure down, with straight edge and plumb-line.
							Distance—6 ft.+5½ ft.+3½ ft.+6 ft.+6 ft.=27 ft.
7	0·00	20·69	..	20·69	465·00	381	Down, 4·33 + 4·45 + 3·39 + 3·32 + 5·20 = 20·69.
8	3·45	2·11	1·34	..	463·66	425	4 ft. high—Roof very jointy and bad—top coal left on.
9	3·97	2·34	1·63	..	462·03	462	4·3 full height of seam, bad roof, closely timbered.
10	2·89	3·86	..	0·97	463·00	507	4·6 „ „
11	2·06	4·49	..	2·43	465·43	555	5·0 better roof, timbered in places only.
12	1·95	4·82	..	2·87	468·30	600	5·0 ordinary height of seam—good roof.
13	3·15	4·15	..	1·00	469·30	657	5·0 „ „
14	4·00	3·37	0·63	..	468·67	705	5·0 „ „
15	4·73	3·03	1·70	..	466·97	780	5·0 „ „
16	3·26	3·84	..	0·58	467·55	840	5·0 „ „
17	2·76	4·71	..	1·95	469·50	885	5·0 „ „
..	61·52 25·94	87·46	8·86 25·94	34·80	..	..	

The Reflecting Level.—For rough surface levelling the reflecting level may be used. It consists of a small sighting-tube, with a bubble-tube set above it. It is so arranged that the bubble is seen through the bottom of its tube, and reflected by a mirror into the sighting-tube. An instrument of this kind, invented by Abney, is also useful as a clinometer. In this instrument the bubble-tube is fastened to an arc 2½ inches in diameter. In taking a level, the vernier, fastened to a bar at right angles to the spirit level, is set to the zero of the vertical arc. On looking through the tube, the object observed will be level with the eye when it is intersected by the bubble. The results obtained are very satisfactory. Like all reflecting instruments, this level is useless in the bad light of a mine.

Sources of Error in Spirit-Levelling.—There are four sources of error in levelling—1, Errors of observation; 2, instrumental errors; 3, errors from unstable supports; 4, atmospheric errors.

Errors of observation are mostly unavoidable, and arise chiefly from the bubble not being carefully centred. Instrumental errors are due to the instrument not being in adjustment, and to the staff not being vertical. Errors from unstable supports can only be eliminated by duplicating the levelling in the opposite direction, and by taking the mean of the results. Atmospheric errors arise from wind, tremulousness of the air in clear sunny weather, and variable refraction due to sudden bursts of sunshine on the line.

A waterproof cloth should be thrown over the level in case of rain. Staves should be wiped dry after being exposed to the rain, placed horizontally to prevent warping, and occasionally compared with a standard length.

Accuracy Attainable in Spirit-levelling.—Mr. W. Seibt arrives at some interesting results, calculated from observations made under ordinary conditions. His telescope of 18-inch focal length had a magnifying power of 42, and an object glass of 1⅝-inch aperture, besides a very sensitive spirit level. The instrument was always set up midway between the back and forward staves, and the observations taken by one central cross-wire; both ends of the spirit level being read at each observation. Observations were only made in still clear weather; the back- and fore-sights being taken as soon as possible after one another. Each complete observation occupied 6 minutes, and 24 pairs of observations were taken at each station. Although the mine-surveyor is rarely in a position to use an instrument as delicate as that described, the results arrived at are of interest for the sake of comparison.

The mean error *m*, in an observation consisting of a back- and fore-reading, was found to be as follows :—

At 50 metres	(164 feet)	±	0·28 millimetre	(0·011 inch).
„ 100 „	(328 „)	±	0·62 „	(0·024 „).
„ 150 „	(492 „)	±	0·71 „	(0·028 „).
„ 200 „	(656 „)	±	0·91 „	(0·035 „).

The distance for observing should be limited by the capacity of the observer and of his instrument. It will always be rightly chosen when it is extended as far as the nature of the ground to be levelled will allow, and on the other hand, when it is so short that no trace of air movement is noticeable through the telescope, and the graduation of the staff is presented as a perfectly stationary and sharply-defined image. If this principle is acted on, it is asserted that the mean error per kilometre should not exceed 0·64 millimetre, as in extensive levelling operations the line of sight does not usually exceed 100 metres.

At the second International Geodetic Conference it was decided that the probable error in the difference of level between two points, 1 kilometre apart, must not, as a rule, exceed 3 millimetres, and in no case exceed 5 millimetres. According to the report of the United States Coast and Geodetic Survey, on the line from Sandy Hook to St. Louis 1,009 miles in length, the probable error per kilometre was 1·2 millimetres.

As an instance of the accuracy attainable in levelling, Captain Henrici, R.E., of the Ordnance Survey, Southampton, stated that the error on two circuits, each between 260 and 300 miles in length was 0·032 foot on one circuit and 0·022 foot on the other. The levelling was performed with a Zeiss level, and specially accurate levelling-staves were employed.[*]

Plotting Sections.—In order to plot a section from the reduced levels as entered in the levelling-book, it is first necessary to rule a straight line to represent the datum-line from which the heights are calculated. Along this line the horizontal distances between the points are marked off, and at each point a line is drawn at right angles to the datum-line. Along the lines thus obtained, the vertical heights are marked off, the figures given in the "reduced levels" column being used for this purpose. In marking off on the datum-line each distance separately, any error made is carried forwards. To remove this source of error, it will be found advisable to add the measured lengths together so as to obtain the absolute distance of each station from the starting point.

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[*] *Trans. Inst. of Min. Eng.*, vol. xlvi., p. 303.

As a rule, in plotting a section two scales are used, one for the horizontal distances, and the other for the vertical heights and depths. An exaggerated representation of the section is thus obtained. By making the vertical scale much greater than the horizontal one, the depths of cutting and embankment required are shown with greater clearness than if both scales are the same. The section shown in Fig. 113 is plotted on a horizontal scale of 3 chains to the inch, and a vertical scale of 30 feet to the inch.

Sections of the main ways in collieries are usually plotted on a horizontal scale of 2 chains to the inch, and a vertical scale of 20 feet to the inch. As a rule, the scale for the horizontal distances should be the same as that of the plan with which it corresponds.

Sections may be plotted with great rapidity by means of Marquois scales. These consist of a right-angled triangle, the hypothenuse of which is three times the length of the shorter side, and two rectangular scales of equal parts, each with two scales, a so-called artificial scale placed close to the edge, and a natural scale immediately within this. The divisions on the artificial scale are three times the size of those on the natural scale. The latter is a simply divided scale of equal parts, with the divisions numbered from left to right. In the artificial scale the zero is placed in the middle of the edge of the rule, and the divisions are numbered both ways from that point to the two ends of the rule. A pair of Marquois scales usually has scales of 30, 60, 25, 50, 35, 45, 20, and 40. The triangle has a short line drawn perpendicular to the hypothenuse near the middle to serve as an index.

To draw a line parallel to another, one of the rulers is laid on the paper, and the short side of the triangle placed against it, when parallel lines may be drawn by sliding the triangle up or down.

To draw a line perpendicular to a given line from a given point in it, the shortest side of the triangle is made to coincide with the given line, and the ruler placed against the hypothenuse. The triangle is then slid along the rule, until a line drawn along the longest side of the triangle passes through the given point.

With these scales the sight is assisted by the divisions on the artificial scale being so much larger than those of the natural scale to which the section is drawn, and any error on the setting of the index produces an error of but one-third the amount in the section.

For the purpose of receiving the plotting of sections, a special kind of paper is prepared, on which faint lines are printed, dividing it horizontally and vertically into one-twentieths of an inch. By the use of this section-paper, much time is saved, as no scale is required.

The Water-Level is a very simple instrument, which, when necessary, may take the place of a more elaborate levelling-instrument. It requires no adjustment; it may be made by any intelligent workman at very slight expense; and in short distances no serious error can be made when using it. It consists of a horizontal tube made of tin-plate or brass, terminated at each end by a vertical glass tube in which the surface of a liquid gives a horizontal line. By means of this line, the vane of a levelling-staff is adjusted to the right height. The tube is made so as to revolve on a light portable stand.

A water-level (*chorobates*) is described by Vitruvius (*de Architectura*, viii. 6), as used in the construction of the Roman aqueducts. It consisted, not of a tube, but of an open trench 5 feet long, 1 inch wide, and 1½ inches deep, cut in a plank 20 feet in length. It was adjusted until the water was at the same height from the top at each end. The plank was provided with legs accurately at right angles to it. They were of equal length, and rested on the line to be levelled.

The water-level was in common use in the Derbyshire lead-mines in the 17th century. The method of levelling then employed is described by Thomas Houghton, writing in 1681, as follows:—

"The Instrument for this purpose may be like the following—viz., a Water Stand, with one or more Channels, which the Miner may make himself, upon an old season'd Joyce, cutting a Mortess therein, a yard long, or more, as his own Discretion directs, plaining the same very well and even."

The observer sights through a hole above the water channel, at a staff 6 yards long; the staff being moved until the top of it can be seen. The instrument is then moved to the place occupied by the staff, and the operation repeated, "till you have finished the whole, and come to the Place where you intend to begin your Sough (adit level): then reducing your Poles into Fathoms, compare them with the depth of your Mine, and thus you may know whether it will lay it dry or no."

A modification of the water-level has recently been employed with success by Dr. Luigi Aita, of Padua. His instrument consists of two levelling-staves, in front of each of which a glass tube, 7·87 inches long and 0·79 inch in diameter, slides up and down. The two glass tubes are connected by an india-rubber pipe, 30 yards in length. At one end of the india-rubber tube is a stopcock, by means of which the connection between the two glass tubes may be interrupted. When in use, one glass tube and the india-rubber pipe are filled with a coloured liquid, the staves are set up at the two stations, and the glass tubes raised approximately to the same height at both staves. The stopcock is then carefully opened, the fluid will stand at the same level in both glass tubes, and its position can be read at both staves. With this instrument a mile may be levelled in six hours. For levelling in narrow, crooked, and partially fallen-in workings, this instrument offers great advantages.

In mines where the seams are thin and inclined, the use of the telescope-level is attended with great inconvenience. For this work, Mr. T. L. Galloway and Mr. C. Z. Bunning * have introduced a modification of Aita's water-level. The apparatus consists of two glass tubes connected by an india-rubber pipe, which may be of any convenient length from 10 yards upwards. Each glass tube is attached to a scale graduated into feet, tenths and hundredths in the same way as the ordinary levelling-staff. The tubes are filled up to the centre of each scale with coloured water. The scales being held vertically upon any sloping surface and at any distance apart that the length of pipe will admit, the difference of level between the stations at which the scales are held will be represented by the difference of the readings denoting the position of the coloured liquid in each tube.

In order to remove the source of error arising from the presence of air-bubbles in the liquid, a stopcock is fitted at each end of the india-rubber pipe. These stopcocks being closed under water prevent all oscillation while the apparatus is being carried from station to station, so that there can be no possibility of the intrusion of air-bubbles. Falls of stone, sudden bends in the road, or timbering, obstacles so frequently interrupting the line of sight in levelling underground, present no difficulty with this apparatus, as it is obviously as easy to proceed over or around any obstacle as to advance in a straight line. The instrument has been used in mines under the most difficult circumstances, and has been found to answer in all cases exceedingly well, the saving in time being very considerable.

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* *Trans. N. Eng. Inst. M.E.*, vol. xxvii., p. 3.

Trigonometrical Levelling.—The trigonometrical method of levelling is based on the solution of a right-angled triangle A B C (Fig. 100), of which the base B C and the angle B C A are known. The difference of level B A of the points A and C will be equal to the base B C multiplied by the tangent of the angle B C A. This method is less exact than spirit-levelling, because a small error in the angle may give rise to a considerable error in the difference of level.

Any instrument with a vertical limb may be employed for levelling trigonometrically. A series of angles of depression and elevation are taken along the line of section, the instrument being sighted to a staff with a vane or a cross-piece fixed to it at exactly the same height from the ground as the centre of the axis of the telescope is. The staff must be held vertically while the observer measures the vertical angle which the line of sight makes with the horizon. The instrument and staff are then made to change places, and the vertical angle determined. The mean of the two readings is taken as the correct result. The distance must then be measured. As the distance is the hypothenuse of a right-angled triangle of which the perpendicular is the difference of level, the latter is obtained by multiplying the measured distance by the sine of the angle observed. The necessary computations can be very readily performed by the use of traverse tables, the columns for departure corresponding to the sines of the vertical angles.

The following is an example of the field record:—

LEVELLING BY VERTICAL ANGLES WITH THE THEODOLITE—1.

From	To	Inclined Lengths in Feet.	Vertical Angles.	Rise.	Fall.	Reduced Levels.	Horizontal Lengths.	Total Distances.	Remarks.
2	1	471·0	7° 21′ R	60·24	..	110·24	467·09	467·09	Starting pt. is 50·00 ft. above datum.
2	3	192·5	3° 11′ R	10·68	..	120·92	192·19	659·28	
4	3	313·5	5° 15′ F	..	28·68	92·24	312·18	971·46	
4	5	340·0	1° 47′ F	..	10·57	81·67	339·83	1311·29	
6	5	368·0	2° 18′ F	..	14·75	66·92	367·66	1678·95	
				70·92	54·00	66·92			
				54·00		50·00			
				16·92		16·92			

When the line to be levelled is marked out on the ground by stakes set at a horizontal distance apart of 100 feet, the height will be found by multiplying the horizontal distance by the tangent of the angle of inclination. The form of record in this case will be seen below.

In this section, in six stations a height of 145 feet has been ascended in equal distances of 100 feet. With a spirit level and a 12-foot staff, the number of stations would have been doubled. In order to simplify the calculations with this method of levelling, Mr. A. Faul, of Baltimore, has computed a table of heights* for all angles from 0° to 22½°, in minutes, for any distance required. His object is to bring levelling by vertical angles into more general use, and save the many stations required in spirit-levelling. The latter method is very tedious in hilly countries where extreme accuracy is immaterial, especially so in all preliminary surveys. The method of levelling by vertical angles gives approximate results in the shortest possible time.

LEVELLING BY VERTICAL ANGLES WITH THE THEODOLITE—2.

From	To	Horizontal Lengths measured in Feet.	Vertical Angles.	Rise.	Fall.	Reduced Levels.	Remarks.
1	0	100	9° 45′ R	17·18	..	117·18	Starting pt. is 100 ft. above datum.
1	2	100	7° 15′ R	12·72	..	129·90	
3	2	100	9° 30′ R	16·73	..	146·63	
3	4	100	10° 15′ R	18·08	..	164·71	
5	4	100	3° 30′ F	..	6·12	158·59	
5	6	100	8° 45′ R	15·39	..	173·98	
7	6	100	8° 30′ R	14·95	..	188·93	
7	8	100	10° 00′ R	17·63	..	206·56	
9	8	100	11° 15′ R	19·89	..	226·45	
9	10	100	12° 30′ R	22·17	..	248·62	
11	10	100	1° 45′ F	..	3·06	245·56	
				154·74	9·18	245·56	
				—9·18		—100·00	
				145·56		145·56	

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* *A Short Treatise on Levelling by Vertical Angles with Tables of Heights.* New York, 1886.

Levelling may be performed by the theodolite by setting up the instrument at the foot of a steep incline, with the line of collimation set at a known angle of inclination. Sights are then taken, as if with a spirit level. Thus, suppose that the theodolite is placed at A, Fig. 65, and that *b* A *c* represents the inclined line of sight. Then B *b*, C *c*, and the other vertical lines will represent the heights read off the staff. The requisite data for drawing the section are thus obtained. This method saves time in taking the levels of steeply inclined ground.

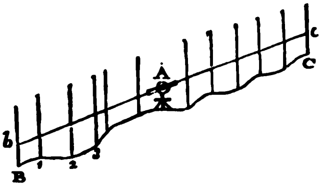

Fig. 114.

When a proper levelling-instrument is not available, the line of collimation may be placed horizontal, and the theodolite used in the same way as the spirit level.

The Clinometer.—For exploratory work, where great accuracy is not required, the clinometer is of great value, on account of its portability. There are numerous forms of this instrument; the commonest resembles a jointed foot-rule, with an inlaid spirit level and sights on one arm, and a divided arc at the hinge to indicate the angular degree of opening. It is set level on a

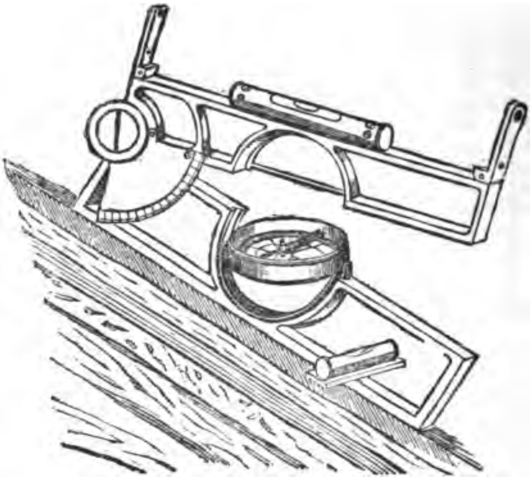
Fig. 115.

stand, and the hinge is opened until the object is seen through the sights. The angle of inclination is then read.

The best instruments of this kind are provided with a 2-inch compass attached on pivots to the lower arm. The clinometer should have a spirit level attached to each arm, and folding sights, and should screw on to a portable tripod, provided with a ball-and-socket joint. In this form, the instrument is practically a miner's dial, on account of its portability well adapted for prospecting purposes.

In the clinometer, manufactured by Messrs. J. Davis & Son, several improvements have been introduced by Prof. H. Louis. The compass pivots are carried on a brass arc capable of revolving in the lower portion of the clinometer frame, so that the compass can be placed horizontally and read without regard to the position of the lower limb. In this way, the dip and strike of strata may be read simultaneously. The compass, too, may be reversed so that the same end of the needle may be used for all dial readings in running lines up and down hill. A further improvement consists in mounting the spirit level of the lower limb on a swivel, so that the instrument may be levelled both ways without being reversed. The clinometer (Fig. 115) is 6¾ inches in length, ½ inch in width, and 3 inches in depth. It weighs 1 lb. 2 ozs., and is mounted on a tripod (Fig. 116), which is provided with a ball-and-socket joint, and which is 3 feet 10 inches in length and 1 lb. 8 ozs. in weight.

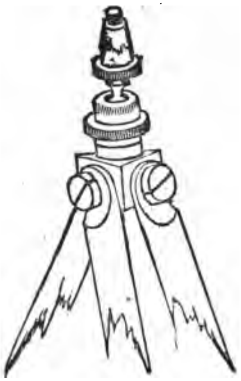

Fig. 116.

A simple and efficient instrument for exploratory work is the pocket altazimuth made by Mr. L. Casella, of London. In this, the clinometer consists of a graduated weighted disc. There is also an azimuth compass with an aluminium disc. Both discs are held by catches, and, when released, are read by a microscope. An excellent telescope is provided for sighting, the instrument being held vertically for altitudes, and horizontally for azimuths.

Physical Levelling.—The application of the barometer to the measurement of heights is based on the fact that for a constant temperature, the density of the air is proportional to the pressure which it sustains. Since the atmospheric pressure decreases as we ascend, it is obvious that the barometer will keep on falling as it is taken to a greater and greater height.

The *mountain barometer* is an ordinary barometer tube, made as portable as possible, and protected against external injury. When in use it is mounted on a portable tripod, and when not in use it is packed in a leather case. The mercury is contained in a wooden cistern at the lower part of the instrument. A screw compresses the mercury and forces it, when required, up to the upper portion of the graduated tube. By means of a vernier, the height of the column of mercury may be read to the one-thousandth part of an inch. Attached to the barometer is a thermometer, enabling a correction to be made for temperature. This correction is necessary because the air and the mercury are unequally expanded by heat.

The simplest barometric rule is as follows:—Observe the height of the barometer in inches at two stations. Then, as the sum of the two readings is to their difference so is 55,000 to the difference between the height of the stations stated in feet.

For example.—What is the difference in level between two points at which the barometers read 30·014 inches, and 29·870 inches respectively? The thermometers read the same at both stations.

$$\text{Difference in level} = 55{,}000 \times \frac{0{\cdot}144}{59{\cdot}884} = 132{\cdot}3 \text{ feet}$$

To correct for temperature, add $\frac{1}{440}$ of the result for each degree, that the mean temperature of the air at the two stations exceeds 55°. Subtract the same amount if the mean temperature is below 55°. When the upper thermometer reads higher than the lower, $\frac{1}{440}$ of the result must be subtracted when the mean temperature of the air exceeds 55°, and added when it is below 55°.

On the United States Geological Survey, a simple and direct method of hypsometry is in use. In this method, proposed by Mr. G. K. Gilbert,* three barometers are used instead of two. Two of these are placed at points whose heights are known, the third being read at the point to be determined. From the reading of the two barometers at the points of known height, the weights of the intervening air column is deducted, and, both the weight and height of the column being known, its density is computable. The density thus derived is then used in the computation of the height of a second column of air between one of the known points and the point to be determined.

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* *Second Annual Report of the U.S. Geol. Surv.*, 1882, p. 405. In this valuable monograph all the principal methods that have hitherto been employed are fully described.

Levelling by the barometer may be occasionally used for taking flying levels in exploring a district. An approximation, however, is all that can be obtained, even if the most elaborate formulæ are employed. The mountain barometer is a cumbrous instrument. It must be more than 30 inches long, exclusive of the cistern, and the mercury is always troublesome to transport.

On account of these disadvantages, for engineering purposes the mercurial barometer has been to a great extent replaced by the *aneroid barometer* invented by Vidi, and patented in Great Britain in 1844. It consists of a circular box, the face of which is made of thin metal, rendered more elastic by being stamped into concentric circular wave-like corrugations. The box is nearly exhausted of air, and its elastic face supports the pressure of the atmosphere, yielding to it with elastic resistance in proportion to the amount of pressure. The movement is communicated to an index, and registered upon the dial. Aneroid barometers are made of pocket-size, carefully compensated so as not to be affected by changes of temperature, and with double scales, one a barometrical scale of inches, the other a scale of altitudes—that is to say, a scale of differences of altitudes for one given pressure.

When specially constructed for mining use, the instrument is graduated to represent 6 inches of the mercurial column, from 27 inches to 33 inches. This scale enables observations to be made from 2,000 feet below sea-level to 4,000 feet above. The finest divisions of the altitude scale represent 10 feet measurement, which can be divided by a vernier, moved by rackwork adjustment, to single feet. A lens, which rotates on the outer circumference, enables the vernier to be read with facility. The instrument is 4½ inches in diameter, and is provided with a leather sling case. In order to retain the sensitiveness of action of the aneroid, it should be cleaned and tested every two or three years by an instrument-maker.

The principle that the boiling-point of water varies with the atmospheric pressure is sometimes applied for the measurement of heights. The instrument used for this purpose, the *hypsometer*, consists of a thermometer, surrounded by a double-telescopic chamber, and suspended so that its bulb is above the surface of some water in a metal boiler, heated by a spirit lamp. It is thus enveloped in steam when the water boils. The cheap and portable instrument for measuring heights is to be preferred, for its simplicity and certainty, to the mountain barometer. Tables are published by the maker, Mr. L. Casella, of London, giving instructions for using the hypsometer.

Determination of the Depths of Shafts.—In connection with levelling operations underground, it is frequently necessary to measure the depths of shafts. For this purpose, a wire with weights at the end, or the winding-rope with the cage or the kibble, is let down, and the length of the wire or rope measured by means of rods. Or the depth of the shaft may be measured direct by applying rods, chains, or steel bands to the timbering of the shaft. Good results have been obtained by both methods. It is, however, evident that the direct measurement is more trustworthy, though more difficult and tedious, than the indirect method. The measurement must be so contrived that the starting- and end-points can be easily connected with the surface and underground levellings.

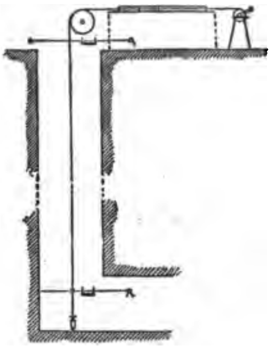

Fig. 117.

The measurement by means of a wire is usually effected by changing the vertical into horizontal measurement in the following manner:—From a small windlass (Fig. 117) erected at a suitable distance from the shaft, the steel wire (piano wire) is unwound, and passed over a pulley, which is placed over the mouth of the shaft in such a way that the wire weighted with 10 to 30 lbs. can without hindrance sink to the bottom of the shaft. The starting- and end-points are distinguished by threads tied on. The depth is measured on letting down and hauling up the wire, and is done most conveniently with the horizontal portion between the pulley and the windlass. The wire is kept in sufficient tension by the weight. The elongation of the wire, caused by its own weight and the attached weight, does not interfere with the accuracy of the result, as the wire is measured in its stretched condition. The method is very rapid; at Firminy, near St. Etienne, a depth of 280 yards has been measured in half an hour. Experiments made at Firminy show that the error with this method does not exceed $\frac{1}{5}$ of an inch per 100 yards of depth. Accurate results have also been obtained at Schemnitz, in Hungary, by Professor Chrismar, who measured in an hour a depth of 210 yards accurately to within $\frac{1}{1500}$ of the measured length.

Local conditions may render it necessary to apply the measure to the vertical part of the wire, in which case the operation is somewhat more inconvenient, but in other respects similar to the preceding.

Instead of the wire, the winding-rope may be used. In this case, the measure is applied to the rope direct above the mouth of the shaft. The results thus obtained are very similar to those obtained with the wire. Thus, Borchers measured one and the same shaft once with the wire and once with the winding-rope; the results being 129 fathoms 3 feet 3⅛ inches and 129 fathoms 3 feet 3·54 inches respectively.

For the direct measurement of shafts, iron surveying-chains, steel bands, or specially constructed measuring-rods are employed.

The chain employed for measuring the depths of shafts must first be carefully tested. It is then let down the shaft at a suitable point, and suspended by the upper handle to a nail. A second nail is driven within the lower handle, and touching it. The chain is then removed, the lower handle being hung to the second nail, and the process repeated as before. The depth thus obtained must be diminished by the thickness of the nails included in the measurement. It is therefore desirable to employ round nails of uniform diameter. The chain, of course, must be allowed to hang perpendicularly, and all obstacles, such as platforms, in the shaft must be removed or bored through. Sometimes it is impossible to measure the shaft in one straight line; a suitable point must then be found in a line at right angles to the chain, and the measurement continued.

With the steel band, shafts are measured in a similar manner. This method has been employed with success by Mr. Graefe * in the Stassfurt salt-mines for measuring shafts of considerable depth. For this purpose, at a measured distance above the roof of the cage, a seat is fastened to the winding-rope in such a way that a miner can sit in it without danger, and apply the upper end of the steel band to the guides. The mine-surveyor stands on the roof of the cage, and carries the lower end of the band. Beside him stands a second workman, whose duty it is to give the signal for raising or lowering the cage. In this way, after all the preparations had been made, the Leopoldshall shaft was measured three times in six hours with the following results:—

First measurement,	. . .	1,095	feet	5·80	inches.
Second ,,	. . .	1,095	,,	5·84	,,
Third ,,	. . .	1,095	,,	5·84	,,

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* *Berg. H. Ztg.*, vol. xlii., 1883, p. 4.

In this case, the heights of 8 levels entering the shaft had also to be determined.

In almost as short a time the Von der Heydt shaft, at Stassfurt, was measured four times; the heights of 7 levels entering the shaft being determined at the same time. The results were—

First measurement,	1,152 feet	2·15 inches.
Second ,,	1,152 ,,	2·07 ,,
Third ,,	1,152 ,,	2·23 ,,
Fourth ,,	1,152 ,,	2·11 ,,

The most accurate means of measuring the depths of shafts are afforded by the measuring-rods constructed for this purpose by Borchers, which are frequently employed in the continental mines. The rods consist of a number of round steel bars 0·16 to 0·24 inch in diameter, and 1 to 4 yards in length. The ends are screwed, and may be connected by brass double screws, so that a measuring-rod of any required length may be constructed. The true end surfaces of the separate rods must be exactly at right angles to the longitudinal axis, and the brass caps are provided with an opening on both sides, so that the contact of the end planes of two rods can be seen. The first rod is provided with a hook, from the inner surface of which the counting commences. On using these rods, the influence of temperature has to be taken into account.

For measuring the depth of vertical shafts, tapes of several hundred yards in length are now largely used. As, however, the absolute length of such tapes cannot easily be ascertained, the results obtained are not faultless. Nevertheless, when a number of vertical shafts are all measured with the same tape, their relative depths can be determined with sufficient accuracy for practical purposes. In mining districts where there are both vertical and inclined shafts, which are measured with different appliances, the determination of the absolute depth is a matter of importance. In the Upper Harz, inclined shafts are always measured by means of Borchers' iron rods, and vertical shafts by means of a suspended wire. Both methods have given satisfactory results. Measuring the wire being a tedious operation, Mr. O. Brathuhn has employed a measuring wheel for the purpose. The brass wheel used had a diameter of 35 inches and a thickness of 0·3 inch, the rim being provided with a rounded groove for the reception of the wire. The periphery of the wheel is divided into a hundred divisions, and with the aid of a pointer and scale a ten-thousandth part of the circumference can be determined. A counter is attached to the axle to register the number of complete revolutions. On the cast-iron bed-plate of the wheel there is a small spirit level, so that the plane of the wheel may be placed vertically. In the plane of the wheel there is a ratchet winch for lowering and raising the wire passing over the wheel. Before the measurement is begun the wire, weighted with a plumb-bob, is passed over the wheel into the shaft, and allowed to hang for several hours until it has stretched to its full extent. For the measurement two levelling instruments are required, one at the surface and the other at the shaft bottom. With the latter the height of a fixed point on the wire is ascertained, and this is marked by tying on a piece of thread. The levelling instrument at the surface is adjusted to sight the wire. The counter is set at zero, and when the thread at the bottom of the shaft has been tied on, the position of the pointer is read, and the wire carefully hauled up. When the thread tied on to the wire is intersected by the cross hairs of the levelling instrument, the wheel is clamped, and the number of revolutions noted. The difference between the initial and final reading multiplied by the value of one revolution gives the required depth. The coefficient of revolution was determined by repeated measurements of a shaft of known depth. Experiments showed that the measuring wheel was a convenient and sufficiently accurate appliance for measuring shafts. Its cost, however, is considerable. The wheel, with winch and guide rollers, costs about £15.

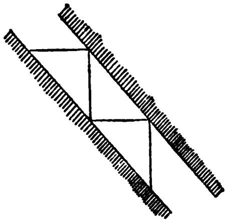

Fig. 118.

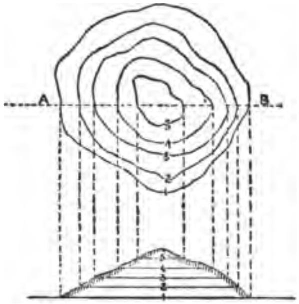

Fig. 119.

The measurement of the depths of inclined shafts presents the greatest difficulties. In such shafts, Fig. 118, a plumb-line is used, the points of suspension being found by means of a spirit level.

Such shafts are frequently tortuous in inclination and in direction, in which case they must be surveyed in the same way as levels, the vertical arc of the dial being employed in conjunction with a plumb-line. It is an operation of great difficulty, and one which in former times has given rise to serious errors in the surveys of the mines of Cornwall, Derbyshire, and the Harz.

In surveying and levelling in the shafts of the Lehigh Valley Coal Company, in the United States, a new form of plummet has recently been adopted. It consists of a vertical core 12 inches long, with eight radiating flanges 9 inches high by 3 inches wide of ¼-inch metal. At the bottom there is a circular disc acting as a web. This plumb-bob weighs 20 lbs., and has a surface area of about 630 square inches. An ordinary bob of equal weight would have a surface of 90 square inches. In a dry shaft, 300 feet deep, this form of plumb-bob will settle, under ordinary conditions, in about one hour instead of in five or six hours, as is the case with the older form.

Contour Lines on the earth's surface are lines traversing all the points on the ground which are at a given constant height above the datum level. A contour line may also be described as a horizontal section of the earth's surface, or as the line where the earth's surface is cut by a given horizontal surface, or as the outline of an imaginary sheet of water covering the ground up to a certain height. Fig. 119 represents the contours of a hill.

Tracing contour lines consists in determining equidistant series of points satisfying these conditions. The vertical distance between successive contour lines on a plan depends on the figure of the ground, and on the scale of the plan. Two methods of tracing contour lines are employed—(1) The regular method, consisting in tracing the lines on the ground, and then surveying them; (2) the irregular method, which consists in collecting, on the ground, data to enable the lines to be constructed on the plan.

In carrying out the former method the simplest procedure can be followed if a level provided with a compass is available. It is necessary to first make a levelling on any line which runs from the lowest to the highest point in the area to be contoured, bench marks being put in at frequent intervals on the line. By computation points on this line can be determined which are at the exact heights of the required contour lines. Each of these points is made the starting point of a traverse, the points of which are all on the same level, their positions being determined successively by setting the levelling instrument up at the starting point and finding by trial a point some distance away which gives a staff-reading equal to the height of the telescope axis. The bearing and distance between the starting point and the point so found are then determined, and the levelling instrument moved forward on to the point and the operations repeated until the line has been traced right through the area. If the telescope of the levelling instrument is provided with subtense wires (see Chap. XVIII.) the operations can be carried out very rapidly.

On the Ordnance maps of Great Britain, on the scale of 6 inches to the mile, contour lines are drawn at each 25 feet of height, with principal contour lines, determined with greater precision, at every 50 feet in the flatter parts of the country, and at every 100 feet in the hilly parts.

Mr. W. F. Howard advocates that colliery plans should exhibit contour lines at regular and frequent intervals. In this way the vertical throw of each fault, excluding the mere bending up or down of the adjacent strata, which has often a tendency to mislead, would be continuously shown though the fault should be rarely penetrated. Contour lines are generally shown on the plans of the anthracite mines of Pennsylvania.

Applications of Levelling.—A branch of engineering, in which the application of levelling is of great importance, is the setting out of aerial wire ropeways. The importance of this mode of transport in the development of mineral resources is known to every mining engineer. As a case in point, the rich iron ores of the Sierra de Bedar, in southern Spain, would probably have remained untouched to this day but for an aerial wire ropeway, 9¾ miles in length, which connects the mines with the shore of the Mediterranean, near the town of Garrucha, and which affords cheap transport to the point of shipment. An ordinary railway would have cost £100,000, whilst an aerial ropeway could be built for about one-quarter of that sum, an outlay which left a satisfactory margin for profits on the sale of the ore.

In the older systems of ropeways, one endless rope is employed, serving both as carrying rope and hauling rope for the buckets. Many examples of lines of this class can be seen in the Bilbao iron ore district. The characteristic of the modern or Otto system consists in the employment of two ropes—a heavy fixed carrying rope and a light travelling hauling rope, the buckets being fitted with special devices for gripping the latter. With ropeways of this class loads of 20 cwts. can be carried, so that as much as 800 tons may be transported in a day of ten hours.

The most important Otto ropeway yet constructed is that for the transport of iron ore at the Aumetz mines in Lorraine. It is 6·67 miles long, with a fall of 475 feet, and transports 500,000 tons of ore annually. The longest wire ropeway in America is that at the Grand Encampment, Wyoming, which is 16 miles long. The highest support is 69 feet high, and there are three wide spans ranging from 1,800 to 2,300 feet. At Garrucha, Spain, the line is divided into four independent sections, the two first being driven by a 30 horse-power engine, and the two last by a 70 horse-power engine. The greatest span of the line is 918 feet, the height above the valley being 164 to 196 feet. The steepest gradient is 1 in 2½, and the tallest standard is 118 feet.

In making the preliminary survey for an Otto wire ropeway, there are several points to which attention should be paid. The terminal points of the line should, whenever possible, be so placed that the ropeway joining them shall be in a straight line, as each turn increases not only the amount of construction necessary, but also the cost of working, as it necessitates the erection of a complete station. For lines of more than 3½ miles in length, one or more intermediate stations must be erected, as greater lengths than this cannot be worked with one hauling rope. At the stations the line can form any desired angle. The points selected for the supports for the bearing-rope should be marked on the ground by wooden pegs distinctly numbered, and should be shown in the section drawn. The supports should be 50 yards apart, when 50 to 100 tons are transported in 10 hours, 40 yards apart for 100 to 600 tons, and 35 yards apart for amounts above 600 tons in 10 hours. This rule may be neglected in crossing roads, in which case one support should be at the side of the road, and it may be neglected when this rule would necessitate the support being placed in a narrow valley or hollow, in which case, in order to avoid unnecessary height, the post may be moved. For crossing valleys and rivers, spans of 350 yards may exceptionally be employed, when supports are impossible or would exceed 35 yards in height. In crossing roads, cross-sections must be made in order to give the required data for the erection of a protecting bridge, and cross-sections must be taken at every point selected for a station.

Marshy sites must be avoided as far as possible; but in cases where this is out of the question, the surveyor must determine the depth to the solid ground.

The hydraulic mining ditches of California afford some interesting examples of levelling successfully conducted in the face of great difficulties. Hydraulic mining consists in the disintegration of auriferous gravel deposits by propelling a heavy jet of water under pressure upon the bank, and in washing off the gravel in sluices in which mercury is distributed. The gold forms an amalgam, and remains caught. This method of mining was introduced in California in 1856, although Pliny describes a system of hydraulic mining in Spain, which resembled in many respects the modern method. Hydraulic mining has given rise to an extensive system of artificial reservoirs in the Sierra Nevada for the storage of water, and to the construction of artificial water-courses to convey the water thus stored to the scene of mining operations. The setting out of these canals at a grade of from 4 to 20 feet per mile, over deep gorges and along precipitous cliffs, presents problems of great difficulty to the mine surveyor. In many places it is impossible to find room along the sides of the great cañons for miles, to excavate a canal or to rest a conduit or "flume," as it is locally termed. The bracket flume of the Miocene mine is a marvellous example of engineering skill. Here, in order to obviate the erection of a trestle 180 feet in height, the water is conveyed in a wooden flume—4 feet wide and 3 feet deep—round a cliff 350 feet in height. The flume is suspended upon brackets made of T-rails, fixed into holes previously drilled in the vertical cliff. In another place, in the line of this ditch, is a piece of breastwork 1,088 feet long and 80 feet high. Again, the Blue Tent Mine has a ditch running for a distance of 6 miles along the face of a cliff, over which the surveyors had to be suspended by ropes 1,000 feet above the bottom of the gorge, in order to establish the line of the flume.

In other places deep gorges are crossed by means of inverted siphons. The Cherokee ditch crosses a deep cañon in this way, the pipe sustaining a columnar pressure equal to 800 feet in perpendicular height. In making the crossing, 12,000 feet of 38-inch pipes, ⅜-inch in thickness, were used. A few years ago there were in California 6,000 miles of mining ditches, their estimated total cost being £3,000,000. Some of them have been built at a cost of £5,000 per mile. The cost, too, of keeping them in repair is very considerable, as the hydraulic miner has constantly to contend with the elements—frost and flood, ice and snow, wind and rain.

In the preliminary survey, to determine the best situation for a long ditch, comparative observations should be made with aneroid barometers, care being taken to determine the elevations, not only of the end points, but also of intermediate points, from which different surveying parties can start on the subsequent setting out of the line. The necessary points being established, the line is staked out, all stations being properly numbered and pegs driven in to indicate the gradient. According to Mr. Bowie, the author of the standard work on this subject, stations may be from 50 to 100 feet apart on ordinary ground; but very irregular country obviously demands shorter intervals. Bench-marks should be placed every ¼ or ½ mile for convenient reference. All details of tunnels, cuttings, and depressions, which require pipes or flumes, should be worked out in full, a work in which the hand-level can often be advantageously employed. Complete notes should be made of the character of the ground along the whole line.

In laying out mining ditches in California it is usual to employ a light frame shaped like the letter A, made of ½ by 1½ inch wood, and provided with a heavy plummet hanging on a fine wire from a notch at the apex. The height of the frame is usually 6 feet, and the base 10 feet. To commence, one end is placed on a level piece of ground, and the other end is raised or lowered until both ends are level, and the plumb-line marks the same position on the cross-bar, if turned completely round. The grade for the proposed mining ditch being decided upon, say, ½ inch in 10 feet, a ½ inch piece of wood is placed under the rear end of the frame, and the point indicated by the plumb-line is marked on the cross-piece. One man then holds the frame, while another lifts the front end until the plummet coincides with the mark, he then drives in a peg in front. The rear end of the frame is then placed exactly where the front end was, and the process is repeated. In this way the ditch can be set out with great rapidity. The only danger lies in getting the wrong end foremost.

On the survey of the Manmad-Dhuha Railway in India, F. R. Johnson (*Min. Proc. Inst. C.E.*, vol. cxv., 1894, p. 343) found that theodolite levelling by angles of inclination proved accurate under very unfavourable conditions, and he is convinced that the theodolite is the best instrument for rapidly exploring rough ground, and for taking a section by angles of inclination. This method gives all the information required in the shortest possible time.

CHAPTER XVII.

CONNECTION OF THE UNDERGROUND- AND SURFACE-SURVEYS.

Methods Employed.—The method employed for connecting the surface- and underground-surveys depends mainly on the way in which entrance to the mine from the surface is effected and on the nature of the standard line of reference for the directions of the lines in the surveys. If the directions of the lines are referred to the magnetic meridian, the determination of the position of a single point common to both surveys is all that is necessary in order to establish the connection between them, as the direction of the magnetic meridian of a place is the same above and below ground. The point of entrance to the mine is usually regarded as the starting point of the underground-surveys, and the position of this is fixed in the same way as any other important point in the surface-survey. The direction of the magnetic meridian is fixed on the plan by means of a meridian test-line (see p. 69), and the plotting of the underground-survey is a straightforward operation.

If the entrance to the mine is effected by a vertical shaft, the starting point of the underground-survey is obtained by plumbing the shaft from the surface. A common practice is to accept one of the winding ropes as being truly vertical, and to fix the position of this by triangulation in the surface-survey, and to start the underground-survey from the winding-rope at the shaft-bottom. In the case of well-constructed shafts this method is well within the limits of accuracy of magnetic traverses. If it is considered advisable to plumb the shaft independently of the winding-ropes, this can be done by means of a heavy plumb-bob suspended by a wire as described later.

Where entrance to the mine is effected by means other than a vertical shaft—*e.g.*, by an adit-level, day-drift, or inclined shaft—the underground traverse can be started from a point at the surface and carried through directly into the workings.

In the case of surveys based on reference lines other than the magnetic meridian, it is necessary that a *line* and not merely a single point be established and incorporated in both the surface- and underground-surveys, this common line serving to correlate the *directions* of all the lines of the surveys. The methods employed for making the connection in such a case again depend on the manner in which entrance to the mine is effected. If entrance is made by an adit-level, day-drift, or inclined shaft, a traverse is started off a line in the surface-survey, the direction of which establishes the directions of the lines in the underground-survey. In the case of traversing through steeply inclined shafts by fixed-needle methods, which, of course, must be employed when the magnetic meridian is out of the question, special precautions have to be taken to ensure accuracy, owing to the peculiar conditions prevailing. The particular points to which attention should be paid are, accuracy in the centring of the instrument at stations and levelling the instrument. In the case of theodolite-surveys, double observations should always be taken, the telescope being transited in between the two sets of readings, so that the effects of the errors in the adjustments are eliminated.

Where entrance to the mine is effected by a vertical shaft or shafts, a line in the surface-survey is transferred to the shaft either by double plumbing or by optical methods. In the case of double plumbing the two plumbets which form the ends of the line may be in the same shaft, or if there are two shafts accessible, then a plumb-bob is suspended in each, and a line of considerable length can thus be obtained leading to accurate results without the necessity for very special precautions in plumbing. Details of a number of possible cases are given in the following pages.

By Means of Two Shafts.—If both the shafts are vertical, the connection of the underground- and surface-surveys is made by means of two plumb-lines, one suspended in each shaft. The points of suspension are joined to the surface-survey by means of triangulation. In this way the length and bearing of the line joining the two plumb-lines may be calculated by means of rectangular co-ordinates. A traverse is then made underground from one plumb-line to the other, and from the data thus obtained the length and bearing

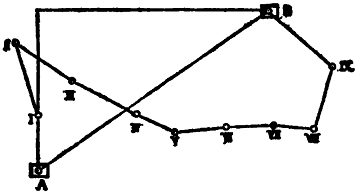

Fig. 120.

of the line joining the two plumb-lines are again calculated by means of co-ordinates.

Example.—In two perpendicular shafts, plumb-lines are hung at the points A and B (Fig. 120). From the surface-triangulation it is found that the length of the line A B is 56·29 chains, and its bearing 118° 36′. In the mine, a traverse was made with the following results:—

From	To	Length, Chains.	Measured Angles.	Angles Reduced to one Meridian.	LATITUDE.		DEPARTURE.	
					N.	S.	E.	W.
A.	I.	1·76	0° 00′	0° 00′	1·76	..	..	..
I.	II.	4·24	177° 33′	357° 33′	4·23	..	..	0·18
II.	III.	13·00	284° 57′	102° 30′	..	2·81	12·69	..
III.	IV.	16·75	177° 56′	100° 26′	..	3·03	16·47	..
IV.	V.	9·30	180° 52′	101° 18′	..	1·82	9·11	..
V.	VI.	8·28	158° 33′	79° 51′	1·45	..	8·15	..
VI.	VII.	3·74	184° 53′	84° 44′	0·34	..	3·72	..
VII.	VIII.	6·32	184° 26′	89° 10′	0·09	..	6·31	..
VIII.	IX.	6·12	93° 53′	3° 03′	6·11	..	0·32	..
IX.	B.	1·18	135° 11′	318° 14′	0·88	..	..	0·78
					14·86 7·66	7·66	56·77 0·96	0·96
					7·20		55·81	

With the co-ordinates 7·20 chains N. and 55·81 chains E., the length and direction of the hypothenuse may be calculated from the formula: $\text{base}^2 + \text{perpendicular}^2 = \text{hypothenuse}^2$, or tangent of angle of bearing $= \frac{\text{departure}}{\text{latitude}}$, and the distance = latitude × secant of angle of bearing. The hypothenuse in the above traverse will be found as follows:—

log 55·81 = 1·7467120
log 7·20 = 0·8573325

L. tan B A C = 10·8893795 B A C = 82° 39′

log 7·20 = 0·8573325
L. sec 82° 39′ = 10·8930271

11·7503596 distance = 56·28 chains.

From this angle—that is, the angle formed by the hypothenuse A B and the first line of the underground-survey A I, and from the bearing of the line A B determined at the surface (118° 36′), the bearing of the first station-line underground may be determined. In the above example, this is done by subtraction, $118° 36' - 82° 38' = 35° 58'$. From this may be deduced the bearing of the other lines of the traverse. In the example, this is done by increasing the reduced meridian angles by 35° 58′ in each case. With the aid of these bearings, the co-ordinates of the underground-traverse should be recalculated, and the results balanced.

For suspending the plummet, a thin annealed wire of iron, brass, or copper is used. Hemp cords are useless for the purpose; because of their torsion and contracting when wet. They present a greater surface to the action of air-currents and water than thin wire, and do not admit of such precise sighting. The weight of the plummet should be sufficient to make the suspending wire perfectly straight, and this will be usually found to be not far off the breaking weight of the wire. The wire should be carefully wound on to reels mounted on suitable frames, so that they can be fixed in position at the top of the shaft. A handle and clamping arrangement should be provided on the reels to facilitate adjustment. By this means kinks in the wire can be avoided and the position of the plummets readily adjusted. The plummet should not be hung on when the wire is let down the shaft in case of accident from the wire breaking. A smaller weight may be used when the wire is being let down, and at the bottom of the shaft it can easily be changed for the required weight. The plumb-line must, of course, hang perfectly free, without coming in contact with the sides of the shaft. To ensure this being the case, a lamp is slowly passed round the wire at the bottom of the shaft. If, in whatever position it is placed, the light can be seen from the top, the wire is clear.

The plumb-lines may be sighted without any difficulty in the surface-survey, as the upper part of each wire does not move. In the mine, however, the plumb-line has to be sighted at its lower end, which continues to vibrate like a pendulum. The motion may be reduced by allowing the plummet to dip into a bucket of water, and by shielding the wire from air-currents and falling water as far as possible. The attachment of wings to the plummet, and allowing the latter to hang in water, is the most satisfactory method of damping oscillations. The wings may be made of thin sheet metal, and the width of each equal to the diameter of the plummet; the length of the wings being equal to the straight portion of the plummet. The attachment of the wings can be made by soldering or rivetting them to rings which can be slipped over the plummet and kept in position by means of two set-screws. Either four or six wings may be used. The buckets in which the plummets are suspended should be shielded from falling water, in wet shafts, by conical hoods provided with a hole at the top through which the wire can be passed before attaching the plummet (see also p. 296).

In sighting a plumb-line with the theodolite, when the oscillation cannot be damped, it is best to follow it by means of the tangent-screw to the end of its vibration. There is then sufficient time to read the vernier before it reaches the other end of its course, as well as to intersect it in that position with the cross-wires. This operation is repeated several times, and the mean taken of all the results. When the arc is very small, the mean may be estimated, and the cross-wires set at that angle direct. The plumb-lines are rendered visible by holding behind them a sheet of oiled paper illuminated by a lamp from behind. This method of sighting a plumb-line is very fatiguing, and necessitates great skill to read the vernier and direct the telescope to the next extremity of the course, in the comparatively short time in which the plummet completes its swing.

These difficulties have been overcome by Professor Schmidt,* of the Freiberg School of Mines. The plummets he uses are hung to thick wire (0·04 inch in diameter), and their weight is considerable, being as much as 50 lbs. They do not dip into water, but are allowed to swing freely. At a short distance above the bottom of the shaft, a horizontal finely-divided scale is placed perpendicular to the line of sight of the telescope. The swinging plumb-line is then observed with the telescope, and the successive extreme positions are read and noted, the plumb-line being purposely made to swing parallel to the plane of the scale. The latter is illuminated by means of an ordinary miner's lamp or candle.

From one or more series of double observations, the mean position of rest of the plummet on the scale is calculated, and for the subsequent survey the cross-wires of the telescope are made to coincide with that calculated point. The calculation of the position of rest is a very exact one. From two trials, one made at a depth of 557 feet under favourable conditions, the other at a depth of 1,722 feet under unfavourable conditions, Professor

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* *Saechs. Jahrbuch.*, 1882, p. 145.

Schmidt found that the mean error of one series of observations was ± 0·12 inch, and the mean error of the result of a double series was ± 0·08 inch. Under unfavourable conditions the errors were 0·17 inch and 0·12 inch respectively.

In cases where it is required to connect the surface-survey with the underground-survey at several levels at different heights in the shaft, it may be desirable to fix the plumb-line. For this purpose, Professor Schmidt* has invented a simple centring apparatus. On a perforated cast-iron plate, a prismatic centre-piece may be slid in two directions at right angles to one another by means of four centring screws. Above the latter are two scales at right angles. The iron plate is placed so that one pair of centring screws is in the line of sight of the theodolite-telescope, the other pair being in the line of sight of a second small telescope of low power. With this small telescope and with that of the theodolite, the swingings of the plumb-line are observed, and the position of rest calculated. The weight is then removed from the plumb-line, and a cap-screw placed on the wire. The weight is then replaced, and screwed into the centre-piece of the apparatus. With the aid of the two telescopes, and the centring screws, the centre-piece can be brought into such a position that the plumb-line is in its calculated position of rest.

If either of the shafts used for connecting the underground- and surface-surveys is inclined, or if both are, the method is the same, except that the shaft is surveyed by traversing instead of by suspending a plumb-line.

The two methods of connecting underground- and surface-surveys by swinging plumb-lines and by plummets provided with wings and dipped into a vessel filled with water or oil, have been combined by Mr. O. Brathuhn, who etches on a glass plate, in addition to the ordinary cross lines, a scale marked with short lines, the divisions having an angular value of 104 seconds. For lighting the plumb-line, a sheet of white paper is held behind it and illuminated by a lamp. Trials of this eye-piece scale have given surprisingly accurate results.

In connecting underground- and surface-surveys with the aid of plumb-lines, iron plumb-bobs with wings of sheet-iron are largely used. Such plumb-bobs may, however, in some circumstances, give rise to erroneous results. In plumbing a shaft 130 yards deep, the error was found by Mr. O. Brathuhn to be considerable. In a south-westerly direction from the shaft a cross-cut had been driven, in which, in addition to the ordinary rails laid down, a large number of spare rails were stored so close to the shaft that one plumb-line hung in close proximity to the northern end of the rails. By the induced magnetism of the rails the plumb-line was drawn from its perpendicular position to such an extent that the distance between the two plumb-lines was 7·5 millimetres greater underground than at the surface, and that the line connecting the plumb-lines at the points of suspension formed an angle of 6 minutes with that at the bottom of the shaft. The error was eliminated by the employment of brass plumb-bobs.

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* *Berg. H. Ztg.*, vol. xliii., 1884, p. 217.

Where two shafts are available, the connection should always be made by this method, even at the expense of some considerable trouble, as the accuracy attainable is greater than is possible in a single shaft, owing to the limited length of the line that can be transferred in the latter case.

By Means of One Shaft.—When there is only one perpendicular shaft, the underground- and surface-surveys may be connected by transferring a short line from the surface to the mine by means of two plumb-lines suspended in the shaft. The bearing and length of this short line may be determined with sufficient accuracy by connecting it with the surface-triangulation. Then, if the underground-survey also includes the line formed at the bottom of the shaft by the two plumb-lines hanging vertically, the connection can be made from the known bearing of that line. Thus, the survey is made at the surface and in the mine in the same way, by constructing a triangle of which the line joining the plumb-line is a side.

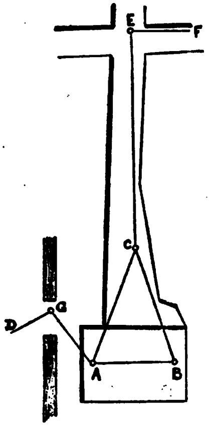

Fig. 121.

The following details of the connection of the underground- and surface-surveys effected in this way may serve as an example:—Fig. 121 is a plan of a portion of a mine, in which D G represents a line at the surface, connected with the triangulation, and E F a line of the traverse of the 135-fathom level of the mine. In order to connect these two lines, two plumb-lines A and B were suspended in the perpendicular shaft, as far apart as circumstances would allow. The distance in this case was 0·9315 fathom. The two wires were sighted from the point G in the doorway of the mine-house, and the angles B G D and A G D and the distances

G B and G A accurately measured. The triangle G A B was in this way completely solved, and the position of the line A B formed by the two plumb-lines was determined with reference to G D. The theodolite was then set up at C in the cross-cut at the 135-fathom level, and with it were carefully measured the angles B C A = 32° 08′, A C E = 159° 21′, and C E F = 269° 31′ 33″, and the horizontal distances C B = 1·6373, C A = 1·7169, and C E = 15·6563 fathoms. Since in the triangle C B A the three sides were determined, it was unnecessary to measure the angle B C A. This was, however, done as a check. On calculation, the angle B C A was found to be 32° 8′ 10″, C A B = 69° 13′ 15″, and C B A = 78° 38′ 37″. Of the measured and calculated values of the angle B C A, the mean 32° 8′ 5″ was taken. The two other angles of the triangle C A B were balanced so as to make the sum of the three angles equal to 180°. In this way the point G at the surface and the point E in the mine are connected by known horizontal distances. The angle which the line D G at the surface makes with the line E F in the mine may then be easily determined.

The line D G being taken as the meridian, the line A B was found from the surface-survey to form an angle of 23° 12′ 10″ with that meridian. Underground the angles formed by the meridian and the various lines were—

A C 69° 13′ 15″ − 23° 12′ 10″ = 46° 01′ 05″
C E 159° 21′ 00″ − 46° 01′ 05″ = 113° 19′ 55″
E F 113° 19′ 55″ − 90° 28′ 27″ = 22° 51′ 28″

In some cases the theodolite may be set up and centred at the points A and B at the surface, but underground this cannot be done with sufficient accuracy.

The accuracy of the connection depends on the correct determination of the angles A and B in the triangle A B C. These angles usually have to be calculated from the known length A B and from the sides A C and C B measured underground, as well as from the angle C. This may be done by the ordinary sine rule—

$$\text{Sin } A = \frac{a \sin C}{c}, \ \sin B = \frac{b \sin C}{c}.$$

In this formula, sin A is dependent upon the three magnitudes C, c, and a. The length c and the angle C may be measured underground with great accuracy.

The influence of an error in the length a on the angle A varies considerably according to the form of the triangle. It is great when the sides *a* and *b* are of equal length—that is, when the triangle A B C is an isosceles one. It is least when the triangle has a very acute-angled form. The sines of angles near 0° and 180° do not increase or decrease in proportion to a slight increase or decrease of the angle. Conversely a small change in the sine has an inappreciable influence on the corresponding angle. Consequently a small error in the length *a* has no effect on the determination of the angle A, when the triangle is an acute-angled one. If possible, then, the ordinary well-conditioned triangle must in this case be avoided, and the theodolite placed as nearly as possible in the continuation of the base-line.

Where the conditions permit it is advisable to arrange matters so that the points G A B C (Fig. 121) are in one straight line. The plummets are fixed first, and the positions of the points A and C found by trial with the theodolite. With an instrument provided with a fine-centring attachment the operation is by no means difficult. If such an attachment is not provided, the points should be made as nearly in a straight line as possible, and the angles at G and C measured by repetition. The influence of the errors in measuring the distances is reduced to the minimum, and, moreover, the calculations are much simplified, as in the case of such small angles as will then be obtained the lengths of the sides are proportional to the angles themselves.

By means of two plumb-lines, the connection between the underground- and surface-surveys has been effected with considerable success by Mr. E. Clark* in the brown hæmatite mines belonging to the Glendon Iron Co. of Pennsylvania. The shafts are usually 4 feet square, but, where an extensive plant of pumping machinery is required, the size is increased to 8 feet by 6 feet. The depth of the shafts varies from 75 to 200 feet. The principal difficulty in the survey of these mines has always been the trouble experienced in connecting the underground-survey with the surface-survey, on account of the small size of the shafts, and the gradual movement of the ground pushing the shafts out of the perpendicular.

The method adopted by Mr. Clark has been to establish a line at the surface, and by means of a straight-edge, wire, and plumb-bob, to project that line to the bottom of the shaft, and there use it as a base-line for the underground-survey. The line across the shaft is marked in the timbers by nails, which may be permanent and used in future surveys, if the earth about the shaft is sufficiently firm. A straight-edge is placed against the nails, and the assistant above lowers the plumb-bob by means of a reel and annealed-iron wire of sufficient strength to hold the plumb-bob, which is of cast-iron, and weighs 10 lbs. The two plumb-bobs are each received into a bucket filled with water at the bottom of the shaft. Vibration may be lessened by mud thrown into the bucket. When the plummets have become nearly stationary, a theodolite is set up in line with the wires. This is done by moving the instrument until the nearer wire coincides with the vertical hair, and the second wire is concealed by the first; or the transit will be in line when the extent of the vibration of the second wire to one side of the first is equal to the extent of the vibration to the other side. The greater the distance between the wires, and the farther the theodolite is from them, the more accurately can it be placed in line. The average distance in 15 shafts surveyed in this way was 18 to 6 inches, this distance being the base-line upon which the mine-survey was based. In the coal-mines of Pennsylvania very good results have been obtained by this method, with a base-line of 9 feet in length.

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* *Trans. Inst. M.E.*, vol. vii., 1879, p. 139.

For rapidly connecting surface- and underground-surveys Mr. T. H. B. Wayne * uses a collapsible triangular frame fitted with levels and legs so that it can be supported horizontally. A telescope and vernier are placed at the apex, and the two legs are recessed at their ends to fit loosely round the two plumb-lines. If the telescope is clamped to a sight at one level, the frame may be transferred to another level where the telescope will give the same direction. An elaborate mechanical device, termed an underlay-table, has been invented by Mr. S. J. Pollitzer,† and used by him with considerable success in surveying zig-zag shafts in New South Wales, the principle being to carry a short horizontal base-line from the surface down to the bottom of the shaft.

The necessity for measuring the relative heights of the various points in a shaft, with a view to preparing vertical sections, induced Mr. Pollitzer ‡ to construct a measuring wire 3,000 feet long. The steel wire used weighed about 2 ozs. per 100 feet. To one end is attached a 9-lb. brass detachable plummet, on which additional weights may be placed if necessary. The wire is marked at each length of 10 feet, and is wound upon a cedar wheel 18 inches in diameter and 1⅞ inches thick. The wheel

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* *Mining Journal*, vol. lxxii., 1902, p. 911.

† *Trans. Inst. M.E.*, vol. xxv., 1903, p. 24

‡ *Ibid.*, p. 17.

can be stopped at any single inch throughout the depth of the shaft. With the aid of this measuring wire Mr. Pollitzer made a survey at a gold mine in New South Wales with a view to making the connection at the 800-foot level between two vertical shafts about 1,000 feet apart. The intervening rock was hard diorite, and in seven months the connection was accurately completed.

In the Missouri lead and zinc mines, where the shafts are frequently out of repair or bent into a curved form, Mr. W. E. Gordon effects the connection by tying the plumb-lines together so as to hang as far apart as possible and yet be clear of the shaft. At the top they led outwardly to posts planted in firm ground, and at the bottom they are tied to the end of a stretcher-bar. This bar accordingly swings into the line of the posts.

In plumbing the very deep shafts at the Tamarack mine, Lake Superior, considerable difficulty has been experienced. The lines were of No. 24 piano-wire, and were lowered carrying a doubly conical wooden frame to prevent catching on obstructions, and 50-lb. plumb-bobs were substituted at the bottom. In one shaft, 4,250 feet in depth, the wires were found to be 17·58 feet apart at the surface, and 17·65 feet apart at the bottom, a difference of 0·84 inch. In another and much shallower shaft the difference was 1·2 inches. This divergence was ascribed to the fact that there is an unbalanced sideways pull on the wires and bobs owing to the missing mass of rock in the shaft. Careful experiments have shown, however, that the phenomena are due to the effect of air currents.

By Means of a Transit-instrument.—The most accurate method of effecting the connection between the underground- and surface-surveys is by means of the transit-instrument.

The transit-instrument is the standard instrument in every astronomical observatory. It consists of a telescope formed of two parts connected by a spherical centre-piece, into which are fitted the larger ends of two cones, the common axis of which is placed at right angles to the axis of the telescope, to serve as the horizontal axis of the instrument. The two small ends of the cones are ground into two equal cylinders or pivots, which rest upon angular bearings or Y's, supported upon standards. One of the pivots is pierced, and allows the light from a lamp to fall upon a plane mirror, fixed in the spherical centre-piece, on the axis of the telescope, and inclined to that axis at an angle of 45°. Light is thus thrown directly down the telescope, and illuminates the cross-wires

The transit-instrument was first used to obtain the connection between the underground- and surface-surveys by Mr. A. Beanlands,* in 1856. The first method he proposed was a purely astronomical one. Having set up the transit-instrument with its plane considerably out of the meridian and its telescope pointed upwards, he observed the passage of several known stars across the wires of the diaphragm in the usual manner. It was found that at the surface the deviation of the plane of the instrument from the meridian could thus be approximately determined. Underground, however, with the telescope pointed up a vertical shaft, it was found that the operation was attended with such difficulty that it had to be abandoned. Instead of observing stars, recourse was had to lights fixed at the top of the shaft. The experiments were perfectly successful, and led to the method identified with Mr. Beanlands' name.

As a matter of convenience it has been found advisable to fix the transit-instrument at the top of the shaft, and to place illuminated marks at the bottom as nearly as possible in the same vertical plane as the instrument. The marks are illuminated by the light of a lamp reflected upwards. They are placed in such a position that they can also be sighted by a theodolite placed in a line with them at the bottom of the shaft. If now the cross-wires of the transit-telescope coincide with each of these two points, it is evident that the horizontal line represented by the marks coincides with the vertical plane of the instrument, and is therefore parallel to the position of the telescope when directed horizontally. In this way two lines are obtained, one at the top of the shaft represented by the optical axis of the telescope pointed horizontally, the other at the bottom of the shaft represented by the line joining the centres of the marks.

If the two marks cannot be brought exactly to the centre of the telescope, the apparent distance of each mark from the cross-wires is measured by a micrometer, and the angular deviation of the base-line from the plane of the transit calculated. The bearing of the base-line is then deduced from that of the instrument, and the connection between the underground- and surface-surveys effected as in the previous case. By this method the bearing of a line underground may be determined with a great degree of accuracy.

As illustrations of the severe practical tests to which this method has been subjected, the following examples may be given :—

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* *Trans. N. Eng. Inst. M.E.*, vol. iv., p. 267; vol. xx., p. 85. See also papers by E. H. Liveing, *Trans. Inst. M.E.*, vol. xviii., 1899, p. 65, and by G. R. Thompson, *ibid.*, vol. xxii., 1902, p. 519.

In 1857, Mr. Beanlands made a survey at Etherley Colliery for the purpose of setting out a drift between the workings of the George Pit, and a new sinking, the Dean Pit, half a mile to the east There was no connection underground between the shafts, and it was therefore necessary to make a surface-survey, and to connect it with the workings at both shafts. At the George Pit, the connection was made by means of a very steep and narrow day-drift, whilst at the Dean Pit, the transit-instrument was employed, marks being left in each case for the purpose of setting out the drift. The latter was worked from both ends : the length being 700 yards. At the end of six months a very accurate holing was effected, the deviation between the two ends being 6 inches. A more convincing proof of the accuracy of this method of connecting the underground- and surface-surveys could hardly be given.

The Pelton Colliery, near Chester-le-Street was worked, in 1864, by two adjacent shafts, 50 fathoms in depth. At a distance of 50 yards from the bottom of these shafts, an underground sinking had been made to explore a lower coal-seam. It was afterwards thought desirable that a shaft should be sunk from the surface immediately above that already existing underground. Mr. Beanlands made a survey for setting out the centre of this shaft. The measurements were made with great care with a levelling-staff, and the connection between the underground- and surface-surveys was effected with the transit-instrument. The shaft was set out from Beanlands' plan, and was found to correspond with the lower shaft within 2 inches.

In shafts of very great depth the method has been employed with most successful results. For example, in the Ryhope Colliery, where the shaft is 253 fathoms deep, the bearing was determined twice in different months, the difference between the two results being only 1′ 10″

As the method requires only one shaft with a clear view from top to bottom, it can obviously be adopted in nearly every colliery. Though a considerable time is necessarily spent in erecting a platform for the transit, a bearing sufficiently accurate for practical purposes may be obtained in a few hours.

The Severn Tunnel Method.—On account of the length of the heading, the incessant jar of the pumping engines and the extreme wetness of the shaft, a plumb-line method was not applicable in driving the Severn Tunnel. The length of the proposed heading was 2 miles, and that of the available base-line 12 feet. Consequently an error of $\frac{1}{20}$ of an inch would become 45 inches at the end of the two miles. To overcome the difficulty, Mr. Richardson,* the engineer, devised the following method:—A large transit-instrument was firmly set up over the shaft, and accurately in the vertical line passing through the centre of the tunnel. This line was determined by two staves, one on each side of the river. The heading having been driven a short distance, a horizontal wire, 100 yards long, was stretched at the bottom of the shaft. One end, A, was attached to the side of the shaft furthest from the heading, the other, B, at a point 100 yards along the heading. A length of 14 feet of wire was visible from the top of the shaft when illuminated by an electric light. The ends of the wire were passed over the V-threads of horizontal screws, and stretched by means of weights suspended from the ends. Thus, by turning either screw, a very fine lateral motion could be imparted to the corresponding end. The transit having been carefully levelled, the end A was first sighted, and the corresponding screw turned until this end was brought truly into the centre line. The telescope was then directed towards the farthest point of the wire visible on the other side of the shaft, and this point also brought into the centre line by turning the screw at the end B, 100 yards distant. The whole length of the wire thus was accurately directed into the line of the tunnel. A base-line 100 yards in length, and practically free from error, was thus obtained. Proof of the accuracy of the method was afforded by the results obtained in driving the tunnel. The headings were found to meet exactly.

By Means of the Transit-theodolite.—In cases where the shaft is of limited depth, and where a large and powerful transit-instrument is not available, the connection between the underground- and surface-surveys may conveniently be effected by means of the transit-theodolite.

The instrument is set up at the bottom of the shaft. To enable its telescope to be pointed vertically upwards, a diagonal eyepiece must be employed. This consists of a small right-angled glass prism (Fig. 122), placed at the eye-end of the telescope, in which the line of sight is reflected from the plane of the hypothenuse vertically upwards.

The mode of procedure is as follows:—Having set up the transit-theodolite at the centre of the shaft A (Fig. 123), it is levelled, and the telescope directed to a small bright light placed on the peg at B. Great care must be taken to ensure the instrument being in perfect adjustment so that the telescope shall revolve in a vertical plane. The vertical circle is then unclamped, and the telescope pointed up the shaft in the same vertical plane in the direction of the point a', where a lamp-flame or a white peg is brought exactly into the line of sight. A permanent mark is placed at a'. The telescope is then directed towards the other side of the shaft, and a mark placed at b'. In this way two points are obtained at the surface in the same vertical plane as the line A B underground. The latter is carefully measured, and the distance thus found is measured off from A′ to C by stretching a cord through the centre of the marks a and b. An iron peg should be driven into the ground at C, with a hole made in its centre for future reference. This hole is directly over the centre of the peg previously driven into the floor of the level at B.

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* *Engineering*, vol. xxxiii., 1882, p. 48

With this method, Mr. H. D Hoskold has obtained, with his miner's transit-theodolite, very satisfactory results in the Dean Forest mines. The method is well adapted for use in mines where the shaft is of limited depth, and the workings not very extensive. The shaft must obviously be of average width, and not subject to any considerable dropping of water.

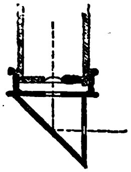

Fig. 122.

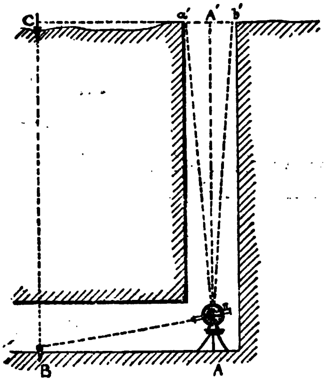

Fig. 123.

For connecting the underground- and surface-surveys, mining transit-theodolites with eccentric telescopes are frequently employed. In these instruments an auxiliary telescope is attached outside the standards to the prolongation of the horizontal axis of the principal telescope, or that telescope itself is permanently mounted in a similar position. Sometimes the theodolite is made with an extra telescope attached to the top of the central telescope, by means of coupling nuts, which fasten it directly over the centre of the instrument, and allow its ready removal without disturbing the adjustments.

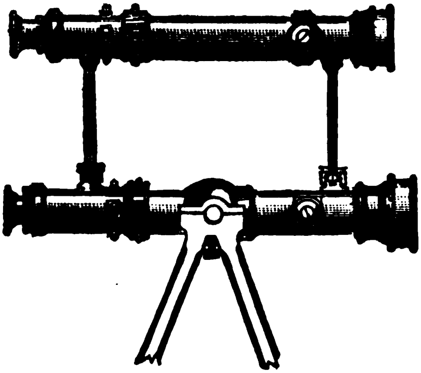

Fig. 124.

This method of arranging the supplementary telescope is shown in Fig. 124. This form is that generally used in conjunction with the American theodolite, shown in Fig. 124. The auxiliary telescope is attached to the main telescope by two

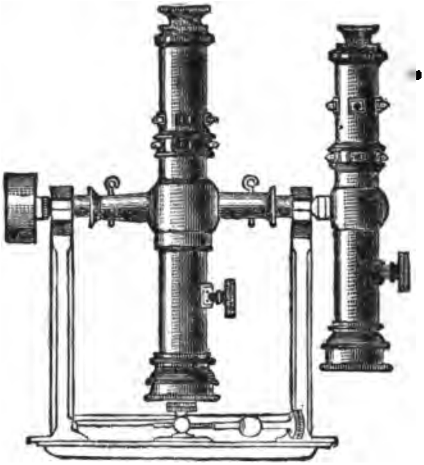

Fig. 125.

pillars, which project beyond the edge of the horizontal plate when the telescope is placed vertically. The method of placing the auxiliary telescope eccentrically is shown in Fig. 125. In this case, a counterpoise is fastened to the prolongation of the axis. In both these attachments, the extra telescope is parallel to the principal telescope.

The objection to the side telescope is that a correction must be applied to each reading of a horizontal angle equal to the tangent of the angle, which is formed by the distance from the side telescope to the centre of the instrument, and the horizontal distance between the stations. This difficulty can also be met by taking two sets of readings transiting the telescope in between. The mean gives the angle from the centre of the instrument.

In a new form of auxiliary telescope designed by Mr. D. D. Scott, the telescope is interchangeable, and may be used either as a side or top telescope; the eccentricity being the same in both positions, and only one counterweight being necessary. The attachment of the auxiliary to the main telescope is effected by means of a single central pillar, which is permanently fastened to the main telescope. If used at the side, the auxiliary telescope is screwed to the end of the horizontal axis.

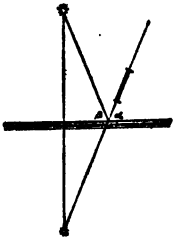

Fig. 126.

In place of the diagonal eye-piece for sighting vertically upwards, an artificial horizon may be used. No special construction of the telescope is then required, as it is merely necessary to sight the image of the flame (Fig. 126). The image and the flame itself are in the same vertical plane, and the image is seen at an angle of depression a equal to the angle of elevation β that would have been observed had the diagonal eye-piece been employed.

The artificial horizon may be made of mercury or of oil mixed with lamp-black. The fluid is filtered through linen, and carried into the mine in a small bottle. When required for use, it is poured into a cylindrical brass vessel, care being taken to protect the surface of the liquid from air-currents.

The artificial horizon will be found more convenient than the diagonal eye-piece for surveying in highly-inclined shafts.

By Means of the Magnetic-Needle.—When the mine has only one shaft, the underground- and surface-surveys may be connected by means of the magnetic-needle, provided that the shaft is not sunk in magnetic strata. If the shaft is vertical, a plumb-line is suspended in the shaft, and from this the underground-survey starts. If the shaft is inclined, a traverse is made down the shaft.

The method of employing the magnetic-needle consists in determining the angle made by one of the sides of a triangle of the surface-survey, as well as that made by one of the lines of the underground traverse, with the magnetic meridian. The lines are then connected by a survey made with the theodolite. The accuracy of the method is increased by observing the magnetic bearings of two or more lines at the surface and underground.

As the whole of the underground-survey depends on the accuracy of the determination of the magnetic bearing of two lines, it is advisable to use the theodolite for that operation. The theodolite is provided with a magnetic-needle, which serves to bring the telescope into the direction of the magnetic meridian. As a rule, in theodolites, the diameter 0° to 180° is in the direction of the telescope. It is, however, not absolutely necessary that the optical axis of the telescope should accurately coincide with that diameter, provided that all the magnetic measurements in the survey are made with the same instrument. If two instruments, say a dial and a theodolite, are used in the same survey, magnetic measurements can be correlated by taking careful observations of a line with both instruments and applying any observed difference in the readings as a correction. Modern mining theodolites are usually provided with a form of compass known as a *trough compass*. This consists of a long narrow box, provided with an index-line, Fig. 127, and has the advantage of not being in the way. The needle should be as light as possible with thin points, and its centre of gravity must not be too low down below the point on which it rests. A magnifying-glass is used to see when the needle exactly coincides with the index-line.

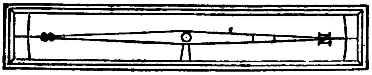

Fig. 127.

The *tubular compass* is very convenient for mine-surveying purposes. It consists of a tubular case, the north end of which is closed with ground glass, on which a fine scale is marked. By means of a lens at the south end of the tube, this scale appears slightly magnified. In front of the scale, swings the north-seeking point of the needle, which is bent upwards, so that it can easily be read with precision in the mine. This compass can easily be adapted to any form of theodolite, as it is not necessary to read it from above, but by looking through it in the same way as a telescope.

With this compass, only one end of the needle is seen. To obviate this disadvantage, Mr. Hildebrand* has devised a new form of tubular compass (Fig. 128). In this, both ends of the needle are seen at once, magnified ten times, the graduation also appearing magnified to the same degree. The compass can easily be read to a single minute in the mine, the light of a candle at a distance of a yard being sufficient to illuminate the scale. The tube is rectangular, and in it a magnetic-needle, 4·32 inches long, swings on a steel point. Close by the south end of the needle is a glass micrometer, and in front of that is a micrometer eye-piece magnifying ten times. Between the south end and the centre of the needle is a small telescope object-glass. By means of the eye-piece, the glass micrometer and the south end of the needle are seen magnified ten times, the magnified inverted optical image of the north end, formed by the object-glass, being also visible. In other words, by means of the eye-piece both the north and south ends of the needle are seen passing before the glass micrometer. The latter is divided into tenths of a millimetre, one division as seen through the eye-piece consequently appearing equal to one millimetre. The middle line of the scale, the zero line, is lengthened in both directions. When the needle is properly adjusted, the images of the south end and of the inverted north end will appear on that line. But if the needle gets out of adjustment, its centre and its north and south points are no longer in the same plane, and the two ends will not coincide with the zero line. The compass must then be so placed that the two ends of the needle appear at the same distance from the zero line. The north end of the compass case is protected from dust by a glass-plate, in front of which is hinged a plate of ground glass, by means of which the artificial illumination is assisted.

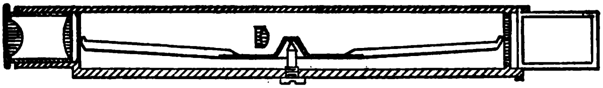

Fig. 128.

As the magnetic meridian is continually changing, it is advisable that the observations at the surface and underground should be made as nearly as practicable at the same time of day or night, and as short a period of time as possible should be allowed to elapse between the observations.

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* *Min. Proc. Inst. C.E.*, vol. xxxvi., 1886, p. 459.

If a considerable interval elapses between the observations, the magnitude of the changes in the magnetic meridian must be observed, and the error thus arising eliminated by calculation. A knowledge of the absolute declination of the needle is not indispensable. If the surface and underground observations are taken at different times of the day it is important to determine the diurnal variation. This can only be done with sufficient accuracy by means of a magnet suspended by a long thin silk fibre, provided with a contrivance for observing the vibrations by means of a telescope. Magnetic-needles supported on pivots, as in the miner's dial, do not admit of sufficient accuracy.

Two contrivances are used for observing the vibrations of the magnetic-needle—(1) Attached to a cylindrical magnet, suspended by a silk fibre, at the north end is a glass plate with a small photographic scale, and at the south end is a small achromatic lens. The centre of the glass-plate is in the principal focus of the lens, so that the line joining the middle division of the scale is nearly parallel to the axis of the magnet. The scale is viewed through the lens by means of a fixed telescope. The motion of the magnet can thus be followed by observing the apparent motion of the scale across the cross-wires of the telescope.

(2) Another arrangement is to attach rigidly a mirror to the magnet, so that the perpendicular to its surface is nearly parallel to the magnetic axis. In this mirror, the image of a fixed horizontal scale is observed by means of a fixed telescope, and the angular motion of the magnet deduced from the motion of the scale divisions over the cross-wires of the telescope. This is called the mirror-method, and was first employed by C. F. Gauss in the magnetometer constructed by him in 1830. The magnetic observatory belonging to the Clausthal mines in the Harz is arranged in accordance with this method. A Gauss magnetometer is undoubtedly the best means of observing the variation of the declination. The cost, however, puts it out of the reach of most mine-surveyors.

A small magnetometer may be constructed of ordinary surveying instruments. With a second theodolite or a levelling instrument, the readings can be effected, and a scale can be prepared. There is then only necessary a magnet with a mirror. It is not absolutely necessary that the mirror shall be perpendicular to the axis of the magnet. It may be attached at any point of the magnet, suited to the station at which the telescope is placed.

A portable magnetometer, on the collimation principle, invented by Professor Borchers, has been used with great success in the German mines. It consists of a magnet suspended by a silk fibre, provided with a lens and scale, and enclosed in a glass case. It is attached by a brass arm to the tripod head of the theodolite.

The use of a somewhat similar instrument has been advocated by Mr. R. S. Newall.* In this, however, the needle is mounted on a pivot instead of being suspended by a silk fibre. Attached to the centre of the needle at right angles to its axis is a small mirror, whilst a minutely graduated scale, consisting of a short length, about 4 inches, of a circle 3 feet in diameter, is fixed at the eye-end of a theodolite telescope, and so adjusted that the degrees are reflected back to the eye by the mirror fixed on the needle. In this way, the scale is magnified twice, and may be easily read to a small fraction of a degree. The arm carrying the telescope is attached to a circle graduated into 360°, and provided with sights, so that bearings may be taken in the same way as with the ordinary miner's dial.

In the declinometer invented by Mr. A. Fennel a long quartz fibre is suspended in a vertical tube, at the lower end of which a horizontal magnet, consisting of a hollow steel cylinder, is hung. In this tube, which acts as the compass-needle, a small mirror is placed transversely. The instrument is attached to the theodolite so as to stand directly before the object end of the telescope To the latter a short tube is attached, containing a half-lens, an inclined mirror, and a glass scale. Through an opening in the upper part of the tube a ray of light impinges upon the mirror, and is reflected forward through the scale into the body of the declinometer, where it is further reflected by the mirror in the magnet. It then passes back through the half-lens and through the object glass.

In order to lessen the influence of torsion of the quartz fibre on the position of the magnet, it is necessary to make the magnet light, to magnetise it to saturation, and to hang it by as thin a fibre as possible. As it is found that mirrors of 4 millimetres diameter give good images of the objective scale, it is possible to give the tubular magnets an internal diameter of only 5 millimetres, so that with a length of 36 millimetres the total weight of the magnet, inclusive of the tubular holder with hook and mirror, does not exceed 46 grains. The magnets are made of tungsten steel, and are magnetised by a high-tension current. The diameter of the quartz fibre capable of safely supporting a magnet of this kind is less than 0·0004 inch, and a turning of the fibre through 1° causes a deviation of the magnet of less than 1 second.

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* *Trans. N. Engl. Inst. M.E.*, vol. xx., 1871, p. 108

Surveying Deep Shafts.—In the deep mines of the Transvaal the method adopted in the past of transferring the meridian underground has been by plumbing. Mr. A. E. Payne has shown, however, that for a deep vertical shaft a more accurate method is required, owing to errors caused by air-currents. Experiments with a nadir instrument have not met with complete success owing to the difficulties of distinct vision at great depths. The large objective of long focal length required does not come within the scope of the mining theodolite; and it remains to be seen whether experience will demand the construction of a special instrument for the purpose. An instrument of the kind was foreshadowed by Professor Nagel, of Dresden, who constructed a nadir instrument without vertical axis, which could be centred over a shaft by means of a centre plug in the base, which was afterwards removed to leave the opening free for the purpose desired.

CHAPTER XVIII.

MEASURING DISTANCES BY TELESCOPE.

Theory of Telescopic Measurements.—The indirect measurement of distances by means of the telescope is based on the solution of a triangle (Fig. 129). Suppose the instrument to be at A and a graduated staff at B C; then the length A D will be known. if the angle D A C and the height D C are known. Two classes of instruments are employed. In one, the angle B A C, which is called the *subtense angle*, is constant, and the height of the staff D C varies with the distance. In the other, the height of the staff is constant, and the angle B A C variable.

The typical instrument of the latter class is that of Stampfer. This consists of a telescope that may be moved 8° in a vertical direction. Two divisions on a staff, held at a distance, are sighted successively. These embrace a constant height s. By means of a micrometer screw it is easy to determine the angle, through which the telescope has moved in passing from one division to the other. Let a represent this angle, which is equal to the number of turns n of the screw multiplied by a constant c. The angle being small, it may be assumed that $\tan a = c\,n$. The distance required will then be equal to $\frac{s}{\tan a}$ or $\frac{s}{c\,n}$. The constant c is determined by observations along a known distance, and tables are constructed giving the distance for any number of turns given to the screw.

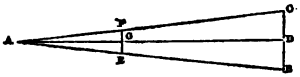

Fig. 129.

The same principle is applied in Eckhold's omnimeter,* an instrument used in revenue surveys in India and in railway surveys in America. In this instrument the measurement of the subtense angle is effected by means of a microscope attached to the axis of the telescope. The reading is taken on a scale of tangents fixed to the horizontal plate of the theodolite.

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* Valuable information regarding the use of this instrument is given by E. W. Young, *Min. Proc. Inst. C.E.*, vol. cxvii., 1894, p. 296.

In American transit-theodolites, a so-called *gradienter* screw is frequently attached to the horizontal axis of the telescope. It consists of a tangent screw with a micrometer head, graduated into 50 equal parts. As the screw is turned, the head passes over a small silvered scale, so graduated that one revolution of the screw corresponds to one space on the scale. Thus, the number of whole revolutions made by the screw in turning the telescope through a vertical arc can be ascertained from the scale. When unclamped, the telescope may be revolved; but when clamped, it can only be moved by the gradienter screw, which thus takes the place of the ordinary vertical tangent screw. The micrometer head is so graduated that one revolution causes the horizontal cross-line of the telescope to move over a space of half a foot at a distance of 100 feet. The micrometer head being divided into 50 parts, each division is equivalent to one-hundredth of a foot in 100 feet. It is evident that, with this screw, slopes can be established with great rapidity.

It is also useful for obtaining approximate distances, since for any horizontal distance, the space on an ordinary levelling-staff expressed in hundredths of a foot, included in two revolutions of the screw, will be the number of feet the staff is distant from the instrument. Thus, if the difference between two readings of the staff is 2·854 feet when the telescope is moved vertically through two revolutions of the screw, the staff is distant 285·4 feet.

On sloping ground, the staff is still held vertical, and the distance read is too great. If a is the angle of elevation, the true horizontal distance may be found by multiplying the space on the vertical staff included in two revolutions of the gradienter screw by $\frac{d}{n\,h} \cos^2 a - \frac{1}{2} \sin 2\,a$, in which h is the height above a horizontal line subtended by one revolution of the gradienter screw at a distance d, and n is the number of revolutions made in any given case. The gradienter screw is usually so cut and placed that when $d = 100$, $n = 2$, and $h = \frac{1}{2}$, the factor then becomes

$$100 \cos^2 a - \frac{1}{2} \sin 2\,a.$$

With the object of reducing the computation to a simple multiplication, Messrs. C. L. Berger & Sons, of Boston, U.S., supply with their transits a table of factors calculated for vertical angles of 0° to 15°.

Instruments in which the angle is constant, and the height of the staff variable, are more important and more numerous. The original instrument of this class is the stadia, invented by James Watt in 1771, and independently by William Green in 1778. An early form of the instrument used in conjunction with the stadia or staff consisted of a tube provided with three parallel wires. In Fig. 129, let G, E, and F represent these wires; G being the axial wire, and E and F the end wires; then the constant angle a will be determined by the height G F, or i, and the distance A G, or r, from the eye-piece to the wires. If A D, the distance to be measured, is represented by d, and if s represents the height of the staff B C, intercepted by the wires E and F, the equation obtained is $d = \frac{r}{i} s$.

The stadia is no longer employed in this primitive form. In Austria, however, a similar instrument is occasionally used in levelling for railway sections. In this the tube is replaced by a pair of sight-vanes, one of which has two parallel wires 0·03 metre apart, stretched across the aperture. The distance from one sight to the other being 0·3 metre, the ratio $\frac{r}{i}$ is equal to 10, so that, in order to measure distances in metres with this instrument, it is merely necessary to use a staff divided into decimetres.

As a rule, the distances to be measured are so great that a telescope has to be employed; in which case the formula is $d = \frac{r}{i} s$, as with the stadia tube; r, however, is not constant, but varies according to the proportion $\frac{1}{r} + \frac{1}{d} = \frac{1}{f}$; f being the focal length of the objective lens.

In the telescopes used in surveying, f is equal to 12 to 15 inches, and r varies as much as 0·24 inch for distances of 20 to 700 yards. Thus, for distances of 100 yards, the variation of r in proportion to the focal length is very slight. It must, however, be taken into account, because r is used as a multiplier.

Various methods are employed for remedying the variability of r. The telescope may be employed like the old stadia tube; the staff being graduated for a single distance, and no corrections applied when the distance is greater or less than this. This method can be used only when great accuracy is not required.

Early in this century, Reichenbach, a Bavarian engineer, proposed a method that is still in frequent use. He eliminated r in the equations $\frac{1}{r} + \frac{1}{d} = \frac{1}{f}$ and $d = \frac{r}{i} s$, obtaining $d = \frac{f}{i} s + f$. The value d, it is seen, is composed of two terms, one being proportional to s and the other being the focal length f. The distance measured from a point as far in front of the object-glass as the focal length of that lens, is thus proportional to s. Then, if the distance is to be reckoned from the centre of the instrument, a constant, c, the distance from the centre of the instrument to the object-glass, must be added. This may be made by the instrument-maker equal to $0{\cdot}5\,f$. The formula is then

$$d = \frac{f}{i} s + f + c.$$

All distances will thus be reckoned from the centre of the instrument, if the sum of the focal length and the distance from the object-glass to the centre of the axis of the telescope is added to the reading at every sight. For example, if the object-glass has a focal length of 12 inches, and the centre of the instrument is 6 inches from the object-glass, 1½ feet is the constant to be added to each reading.

A staff may be graduated to read the distance direct. It is, however, useful only for measuring distances, and not for levelling at the same time. It is preferable to use an ordinary levelling-staff and a telescope, in which the instrument-maker has selected for $\frac{f}{i}$ some multiple of 100. Suppose, for example, that $\frac{f}{i} = 100$. The distance from the centre of the instrument would then be $100\,s$ + the constant. The calculation of distances is thus greatly facilitated.

When the line of sight is inclined towards the staff, the space intercepted is increased in the ratio of 1 to the cosine of the angle with the horizon. Thus, the space s' for the staff perpendicular to the horizon becomes s for the staff when vertical, and, by approximation, $s' = s \cos \alpha$. The inclined distance is then equal to $100\,s \cos \alpha + (f + c)$, and the horizontal distance is equal to $100\,s \cos^2 \alpha + (f + c) \cos \alpha$. But since $(f + c)$ is, at most, equal to 2 feet, when the angle α is small, say up to 5°, $(f + c)$ may be taken as equal to its horizontal projection. The horizontal distance will then be equal to $100\,s \cos^2 \alpha + (f + c)$.

In Germany it is usual to hold the staff perpendicular to the line of sight. The inclined distance is then equal to $100\,s + (f + c)$, and its horizontal projection is equal to $\{100\,s + (f + c)\} \cos \alpha$, or, approximately, $100\,s \cos \alpha + (f + c)$.

The Tacheometer.—The most effectual method of remedying the variability of r is that proposed by Porro, a Piedmontese officer, afterwards professor at Milan, who in 1823 modified the construction of the telescope in such a way as to remove all necessity for adding constants. He introduced between the object-glass and eye-piece a third lens. The function of this "anallatic" or unchangeable lens is to make the size of an object, that forms an image of fixed dimensions, proportional to the distance of the object from the axis of the theodolite, instead of to its distance from the anterior focus of the object-glass as in the case in an ordinary telescope. By this means the intercept of a pair of fixed wires in the diaphragm on a graduated staff is directly proportional to the distance of the staff from the axis of the theodolite. In other words, in consequence of the interposition of the anallatic lens,* the rays coming from the end-wires to the staff, form an angle ω with its vertex at O, the centre of the telescope. The angle ω is termed the diastimometric angle, and O the anallatic point. The angle ω varies with the distance of the anallatic lens from the object-glass. If this distance increases, ω decreases, and conversely, whilst the distance remains constant, ω is invariable. It can readily be seen that the distance from O, the centre of the telescope, can be deduced from the length A B intercepted by the wires. In fact the sides of the diastimometric angle form with the staff virtual triangles, O A B, O A′ B′. These triangles being similar give—

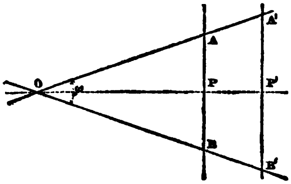

Fig. 130.

$$\frac{\text{O P}}{\text{A B}} = \frac{\text{O P}'}{\text{A}'\,\text{B}'} = k.$$

It is thus merely necessary to determine a simple constant, the diastimometric ratio, and then to move the anallatic lens until ω corresponds to it. As a rule, k is taken as $\frac{1}{200}$, in which case ω is equal to 0·32 centesimal degree. It follows that at 200 yards, for example, the length of staff intercepted should be 1 yard. The diastimometric ratio is represented by the expression $2 \tan \frac{\omega}{2}$. The distance is then $s \div 2 \tan \frac{\omega}{2}$.

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* The theory of the anallatic lens is expounded by A. E. Young, *Min. Proc. Inst. C.E.*, vol. cxxxix., 1900, p. 336.

The original instruments, tacheometers, made by Porro were very favourably reported on by a French Government Commission. Their extremely delicate nature, however, prevented them from coming into general use.

In 1856, M. Moinot gave the tacheometer a form resembling that of the larger modern theodolites. His instrument is based on the same principle as that of Porro, but is much less delicate and less expensive, while giving results of great accuracy. Like Porro's original instrument, Moinot's tacheometer permits distances to be measured at the same time as angles and differences in level. Its use has led to a new method of surveying for railway purposes, termed tacheometry, which is quite as accurate as the older method of longitudinal- and cross-sections. By the advantages it presents of greater rapidity, and the small number of assistants required, this method has undoubtedly contributed to the development of railways, notably in mountainous districts. The aim of tacheometry is to survey and level simultaneously a tract of ground with the greatest possible accuracy in the least possible time. In mountainous districts, it is a method of the greatest value, since it dispenses with the chain and spirit level, and thus the laborious, slow, and expensive processes of chaining over bad ground and of levelling up and down hill, are avoided. By means of a single observation, the distance, azimuth, and height are determined of every point visible and accessible from a given station point. In this way, surveys are made in one-third to one-fifth of the time that is required for the older methods. Since its first application by Moinot in 1856, on the line from Nice to Genoa, it has been employed in most of the continental countries, excepting perhaps North Germany. There Reichenbach's method is still used; instruments being constructed under the name of tacheometers, more or less similar to Moinot's tacheometer, but without the anallatic telescope.

The tacheometer is so constructed that $2 \tan \frac{\omega}{2}$ is equal to $\frac{1}{200}$. The distance being equal to $200\,s$ may be read direct from the staff, if the latter is graduated in half-centimetres. Thus, if the lower wire coincides with the division marked 100, and the upper one with the division 110, the height s will be equal to $110 - 100 = 10$ half-centimetres, and the distance will be 10 metres.

In order to reduce the measured distance to the horizontal, the work is always carried on with the staff held vertical, and the angle of inclination of the optic axis is determined.

Any ordinary theodolite having a good telescope and fitted with a subtense reticule may be used for tacheometric surveying. The distances which can be measured with reasonable accuracy are limited by the form of the telescope, thus it may be stated that a 10-inch telescope with a magnifying power of, say, 20 diameters will enable a distance of 300 feet to be measured within a foot. The instrument should be tested over measured distances varying from 100 to 500 feet or even more, if it is provided with a large telescope.

The tacheometer is essentially a theodolite with a concentric distance-measuring telescope. It differs from the theodolite in being furnished with an anallatic lens, and sometimes in being graduated according to the centesimal method, the circle being divided into 400 parts or degrees. For some purposes this division is very convenient. The angles are read more rapidly, on account of the simplicity of the division into tens and hundreds, and since they are read from two verniers, one at each end of a diameter of the circle, errors are at once evident, the readings differing by 200°. Lastly, with the centesimal division, the slide-rule computations are greatly facilitated. Tables of logarithms for the centesimal method have been prepared by Callet, Borda, Plausolles, Laland, and others, and have been in use for many years.

The Staves used in tacheometry are always graduated with sufficient distinctness to be read by the observers. Porro's staff is triangular in section, and has three graduations with different subdivisions according to requirements. For short distances, the divisions are extremely fine; for greater distances only whole metres are marked in bold figures. Moinot's staff is graduated in such a way that it can be used for short or for long distances.

The staff should not exceed 12 to 16 feet in length, and should be made of light wood. During the observation it must be held perfectly vertical. It should therefore be provided with a plumb-line, or, better, with a round spirit level, and a pair of light sliding legs attached to the back of the staff.

Calculations.—For calculating the results of a tacheometer-survey, the slide-rule may advantageously be used. The rule contains scales of numbers, sines, and tangents. To these Moinot has added a scale giving the values of $\sin^2$, the origin of which is so placed that a single setting of the slide gives simultaneously the horizontal distance ($s \sin^2 \varphi$), and the difference of level. By means of these scales, the co-ordinates of points observed from a single station with the tacheometer are rapidly computed, without any direct measurements being made.

The Protractor designed by Moinot for plotting tacheometer-surveys differs from the ordinary protractor, in that it gives at the same time the direction and the distance of the point to be determined on the plan. It is a semicircular protractor, of transparent horn, or of thick paper, provided with a needle-pointed pivot at its centre. Its straight-edge is graduated so that distances can be measured off each way from the centre. Angles are obtained from the graduated semicircle, reading from a point marked on the plan.

The Field-Work.—Tacheometric-surveys are usually conducted by a party of three, (1) the engineer to direct the work; (2) the observer at the instrument; and (3) the recorder to book the results. On level ground two staff-holders are employed, and on irregular ground one or two more are necessary, in order to prevent loss of time to the observer. For less important surveys one observer and one staff-holder suffice.

When the instrument has been set up at a suitable point, staff-holders are sent to all the points to be surveyed. To each point a number is assigned, and noted in the field-book, and on a sketch made at the same time. The telescope is directed towards the staff, and the stadia wires are read and noted in the proper column of the field-book. The horizontal and vertical angles are then read and noted. This operation is repeated for all the points that can be seen from this station.

In this way, for every point three figures are obtained—the distance, and the horizontal and vertical angles. The point is thus fixed by means of polar co-ordinates.

If the survey has to be connected with one previously made, some data from the former work are necessary in order to make the connection. Two points, if accurately determined, are sufficient.

The instrument having been set up and levelled, the engineer makes a reconnaisance of the ground to be surveyed, and gives instructions to the staff-holder, who goes successively to all the points selected by the engineer, and at each one holds the staff steadily vertical until he receives a signal to pass on. The observer at the instrument now makes the necessary observations, which are noted in the field-book by the recorder.

When the ground to be surveyed is so extensive that two stations are necessary, the engineer selects two points visible from both stations. When the observation at the first station is finished, the instrument is moved to the second, and the two points are observed. The connection could, of course, be made by means of one point only. It is, however, advisable to employ two as a check on the accuracy of the work. When a number of stations are required the method is similar. The method described is that used by Porro.

Moinot employs the tacheometer in preliminary surveys for railway lines in the following manner:—Before the belt of ground is surveyed, an extensive reconnaisance is undertaken, and the main direction of the railway determined, so that the survey may be limited to a comparatively narrow strip. On account of the rapidity of the method there is no occasion to be too anxious about limiting the width. A strip should always be selected of sufficient width to allow if necessary a lateral displacement of the line. A width of 400 yards is quite sufficient. Marks are fixed 200 to 300 yards apart, and numbers are assigned to them. For filling in details, points are chosen wherever the ground presents any decided change of level. The instrument is set up at a point so selected that connection can be made with any existing survey or railway. The assistant then gives a signal with a whistle or horn to announce that he is ready. In the meantime the recorder has measured and noted the height of the instrument, and the engineer has made a sketch roughly to the scale of the plan to be prepared, showing all the roads, rivers, boundaries, fields, and the station of the instrument. As soon as he hears the signal, the engineer indicates to each staff-holder his place, care being taken that only one staff is ready at a time. The other staff-holder is still on the road, or, if already at his post, he turns the narrow side of the staff towards the instrument, and remains in this position until it is signalled to him that the preceding reading is finished. He then turns the graduation of the staff towards the instrument, and by means of a signal directs attention to his position. He then awaits the signal that he can pass on.

The assistant at the instrument has to read the upper and the lower wires with each staff, and then the vertical and horizontal angles, and to call them out in this order to the recorder, who notes them in the field-book. The recorder enters the points in order, as 1, 2, 3, etc. At every fifth or tenth point the assistant gives a double signal, whereby the engineer, although at a distance from the instrument, has a check on the accuracy of the booking, seeing that he has entered the points in his sketch in the same order.

In order to economise time, the engineer selects the points in such a way that he comes finally in proximity to the point he regarded as being most suitable for the next station. Here he places a mark and sets up a staff, at the same time giving a special signal to the assistant.

When the readings for this next station are finished, the observations at the first station are complete, and the instrument is carried on. In the meantime, the man who was holding the staff at the new station returns to the preceding one just left by the instrument. The recorder begins a new station in the field-book, and at once enters the height of the instrument in its proper column. A back observation is now taken, and the distance, height, and azimuth should coincide with the results previously obtained.

By the aid of this method, Moinot has surveyed about 1,000 miles for railway purposes. The distances, when measured on the ground with extreme care, have never differed from those shown on the plan by more than one per thousand, and the longitudinal section obtained by accurate spirit-levelling has never presented any appreciable difference when compared with the results afforded by the heights given on the plan.

Field-Book.—The methods of entering the notes of a tacheometric-survey vary considerably. A convenient method is to tabulate in ten columns, headed as follows:—1, Zero station; 2, instrument station; 3, staff station; 4, height of instrument; 5, 6, 7, the three stadia readings, upper, lower, and middle respectively; 8, vertical angle; 9, horizontal angle; 10, remarks.

The Topographical Stadia is a plane table in which the alidade is provided with a telescope fitted with subtense wires. The points are observed from one station, the distances from this being reduced to the horizontal, and the heights calculated on the spot by means of a special slide-rule. The data thus obtained are at once plotted to the scale required on a sheet of paper stretched on the plane table, the height of each point being accurately noted. When the height of a sufficient number of points is determined, contour lines are traced with the ground in view. In fact, the ground is practically sketched from nature.

An instrument devised by Professor Henry Louis, D.Sc., for use with the topographical stadia in hilly countries has proved very satisfactory in practice. This consists of a pair of proportional compasses, the special feature of which is the method of graduation. The graduations are arranged so that after setting the index to the vertical angle measured on the alidade, and setting the points of the long arms of the compasses to the distance on the slope (which is obtained directly from the telescope readings), the corrected distance is given by the points of the short arms, and can be plotted directly on this plan. The instrument is not intended for use when contouring.

On the United States Coast and Geodetic Survey, the plane table has been exclusively used for making topographical surveys; the stadia, or *telemeter* as it is called on that service, being used in connection with it. The stadia is graduated experimentally for the particular instrument, and for the eye of the observer who has it in use. It is simply a scale of equal parts painted upon a wooden staff, about 10 feet long, 5 inches wide, and 1¼ inches thick, so graduated that the number of divisions, as seen between the horizontal wires of the telescope, is equal to the number of metres in the distance between the observer's eye and the staff held perpendicular to the line of sight.

American experience tends to show that the plane table is adapted to open country and long distances, where no contour lines are to be determined, and where the stations are comparatively few, as well as where a multiplicity of detail is required. Against the advantage of plotting the work in the field may be placed the disadvantages of having no record but the field-sheet, which is liable to be spoiled in a storm.

Accuracy of Tacheometric-Surveys.—Valuable information as to the accuracy of this method of surveying is given in the report of the United States Lake Survey for 1875. The entire stadia work of that year was co-ordinated, and compared with the corresponding distances obtained by triangulation. In this way 141 lines, on an average 1½ miles in length, were tested, the average error being 1 in 650. The distance between the stations averaged 800 to 1,000 feet. The limit of error allowable in closing on a triangulation was 1 in 300. The readings were taken to the nearest metre; the staves were graduated for a single distance; and no corrections were applied when the distance read was greater or less than this. Had more care been exercised in the work, the readings limited to 1,000 feet, and all corrections applied, it would have been easy to bring the error within 1 in 1,200.

This method was used by Mr. W. B. Dawson in 1882 for the preparation of a map of the gold-field on the Atlantic Coast of Nova Scotia, on a scale of 2 inches to the mile. The traverse lines ran along the roads and principal streams, forming a network of quadrilaterals, and were plotted by co-ordinates. The instruments used in the survey were a Sopwith levelling-staff, and a 6-inch transit-theodolite with a 4½-inch compass-needle. The telescope was fitted with three horizontal spider lines, unequally spaced, the larger interval corresponding to 100 feet of distance for each foot intercepted by the staff. The smaller one was only used for longer sight, and when the view was obstructed. In five months of field work an area of 180 square miles was surveyed, including nearly one hundred lakes from 7 miles long, downwards, all the work being done by Mr. Dawson with one assistant, and one or two men according to circumstances. Wet days were devoted to the reduction of the observations. The total cost of the survey was 16·75 dollars per square mile.

Atmospheric refraction presents difficulties. Mr. Cooke shows that the atmospheric refraction of the lower line of sight, which traverses air strata close to the ground, is much greater than that of the upper sight, and the effect is variable. With the staff placed horizontally the refraction is equal for the two readings. The best results can be obtained in the early mornings and the evenings when the atmosphere is comparatively still.

Telescope Measurements in Mine-Surveys.—In mine-surveys very accurate readings may be obtained on account of the steadiness of the air. Fron Goch mine, North Wales, was surveyed in this way by an Italian engineer. A transit-theodolite magnifying ten times, with adjustable micrometer wires, was used in 1865 with great success by Mr. B. S. Lyman for surveying in an American colliery. It saved much disagreeable groping in the mud to count the links of a chain, and levels were taken at the same time. The wires were placed so far apart that 1 foot of space intercepted on the staff indicated a distance of 100 feet. The figures on the staff were painted with red ink upon thin paper that had been fastened to strips of common window glass by transparent varnish. Then over the paper another coat of varnish was poured, and upon this was placed another strip of glass. The glasses, with the paper between them, were then put into a narrow wooden frame, which formed one side of a long box. This had neither top nor bottom, and its sides were so hinged together that they folded over upon each other when not in use. The back of the box had holes through it to supply air to the lights, and either safety-lamps or candles were fixed to the wood of the back. The box was made 5 feet in length; but for low mines one might be made much shorter. This staff lighted inside makes telescopic measuring and levelling easy underground, where chaining is particularly disagreeable.

To remedy the difficulty of getting sufficient light to read the ordinary staff, Professor Johnson proposes to use two strips, one-quarter of an inch wide, one of which is fastened with its top even with the zero of the stadia scale, whilst the other is moved to suit the position of the other wire. The reading of the top edge of the upper strip then gives the distance, which is read off by the staff-holder.

Tacheometry is specially adapted for geological-surveys, which have frequently to be made in mountainous districts where chaining is laborious and inaccurate, and where levelling up and down the sides of the mountains is not practicable.*

The Gradient-Telemeter Mining Dial.—The principles of tacheometry have been successfully applied to underground-surveys in the mining dial invented by Mr. J. Short and manufactured by Mr. L. Casella of London (Fig. 131). Like the gradient-telemeter level, of which it is a modification, the dial is furnished with a horizontal limb on which are marked the gradients of 1 in 500 to 1 in 24. The gradient marks are such a distance apart that they can be easily read at the index without the aid of a reading microscope, no vernier being necessary. This, together with the fact that the observation that gives the gradient also gives the distance of the observer's station from the object, enables accurate levelling to be done with remarkable rapidity. A horizontal circle is also provided for fixed-needle dialling. This is read by a vernier to five minutes. Distances are measured or set out by simply reading a levelling staff or a suspended tape placed at the distant position. The instrument has a telescope 11 inches in length with an extra large object-glass 1·7 inches in diameter. It is adapted for surface work as well as for mine-surveys, and can be used as a high-class dumpy-level.

For ascertaining the gradient between two stations, the instrument is set up at the first and levelled with the gradient limb clamped at zero. The height of the centre of the telescope from the ground is then read from a tape hanging from the base-plate of the instrument. A levelling-staff is then held upright at the second station, the telescope directed to it, and the reading taken. If the reading on the staff is the same as that on the tape below the instrument, the two stations are at the same level. If, however, the reading differs, the clamp screw fixing the two axes of the instrument is loosened, and, with the telescope held lightly in one hand, the graduated horizontal limb is moved with the other hand (by means of radial bars or ribs on its under surface) until the cross-wire of the telescope exactly cuts on the staff the same height as that given by the suspended tape. During this operation, the index attached to the telescope will have moved on the graduated limb of the instrument, and, on the reading of the index being noted, the gradient between the two stations will be given without any calculation whatever.

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* For further information on this method of surveying, the student is referred to J. B. Johnston's *Topographical Surveying by means of the Trnasit and Stadia*, New York, 1885; and to B. H. Brough's paper, *Min. Proc. Inst. C.E.*, vol. xci., 1888, p. 282, in which a bibliography of the subject is given. See also papers by N. Kennedy, *Min. Proc. Inst. C.E.*, vol. xcix., 1890, p. 308; by W. Airy, *ibid.*, vol. ci., 1890, p. 222; by R. E. Middleton, *ibid.*, vol. cxvi., 1894, p. 311; by W. Poole, *ibid.*, vol. cxxxix., 1900, p. 259; by H. G. Dempster, *ibid.*, p. 273; by H. P. Seale, *Trans. Australasian Inst. M.E.*, vol. vi., 1900, p. 62; and by A. H. Webb, with discussion by L. H. Cooke, *Trans. Inst. Min. Met.*, vol. xv., 1906, p. 304.

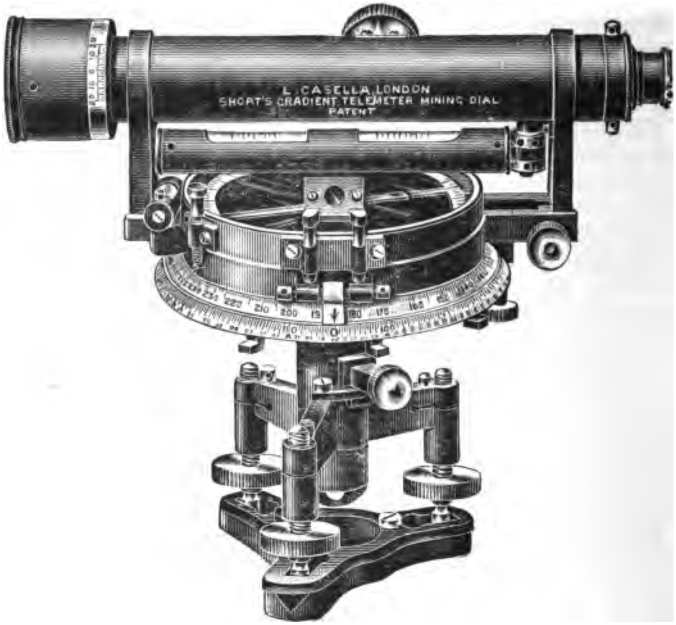

Fig. 131.

A screw attached to the clamp, gives a fine adjustment and permits a very accurate reading of the staff.

For measuring the distance between two stations, the instrument is set up and levelled with the index clamped at zero. An ordinary 14-foot staff divided in hundredths of a foot is then sighted at the second station. Suppose the reading to be 10·68. The clamp is then unloosened and the telescope moved until the index reads exactly 100 on the graduated limb, and fixed there by the clamp. The telescope is then moved round on the outer axis of the instrument, and again read the staff. Suppose the second reading to be 6·42. The difference between the two readings is 4·26, and the distance between the two stations is 426 feet. In other words, eliminate the decimal point from the difference of the two readings, and the figures as they stand give the distance in feet without any calculation whatever.

An extension of the method is to use other gradients, thus—

Gradient	50	and divide the difference by	2.
,,	33½	,, ,,	3.
,,	25	,, ,,	4.
,,	20	,, ,,	5.
,,	16⅔	,, ,,	6.
,,	12½	,, ,,	8.
,,	10	,, ,,	10.

Provided the staff is divided decimally, the metre or any other scale may be used.

For fixed-needle dialling, the instrument is used in the usual manner. It is provided with a 4¾-inch aluminium compass-ring read by a prism. It has a locking plate and three levelling screws, and the telescope cap is graduated for slopes of side sections. The tripod stand is jointed at short length so that it may be used in a 2-foot seam.

The Dunbar-Scott Mine Tacheometer.—Mr. Dunbar D. Scott has successfully applied his idea of an interchangeable and adjustable auxiliary telescope to the mine tacheometer. The instrument is arranged to perform the most difficult problems to be encountered in shaft-surveying without the correction for eccentricity necessary with the earlier types of top or side auxiliary telescope. This is effected by extending the horizontal axis sufficiently far beyond the bearings as to terminate in a threaded hub. Open vertical pillars are cast in one piece with the hub of the main telescope of exactly the same length as the horizontal axis thus extended. The auxiliary telescope has a peculiarly constructed hub, which may be applied to the threaded extension of either the horizontal axis or of the vertical pillars, and rapidly ranged into the same visual plane with the main

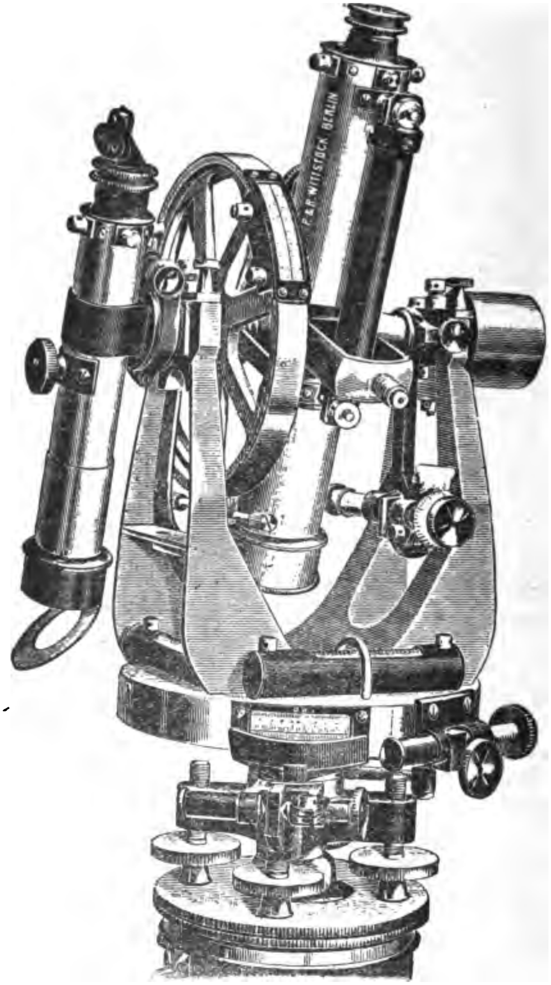

Fig. 132.—Dunbar-Scott Mine Tacheometer.

telescope. Tacheometers on this system are made by W. F. Stanley & Co., London, and by the American firms of Buff &

Buff and F. E. Brandis & Sons. The instrument made by Wittstock, of Berlin, is of a more sturdy type. The dimensions of the instrument shown in Fig. 132 are as follows:—Horizontal circle, 5 inches; vertical circle, 4½ inches; main telescope, 20 to 25 diameters power and 8 inches long; weight of instrument complete, 8½ lbs., and extension tripod 6 lbs. additional. The counterpoise, which is always to be attached opposite the auxiliary telescope, weighs but a few ounces. It always remains in the case, with the auxiliary telescope, except when the special occasion demands their use. In ordinary work the threaded extensions to the pillars and the extended horizontal axis are protected by small caps. The edge graduation of both circles is noteworthy, and the vernier of the vertical circle is very conveniently placed.

The Mayer and Wiesmann Tacheometer.—For surveying operations in the Simplon tunnel, Messrs. Mayer and Wiesmann designed a tacheometer, resembling an ordinary transit-theodolite, but with three additional pieces. On the side of the standards sliding in a slit and to be connected with the telescope by the tightening of a screw, is a vernier which travels backwards and forwards, following the movements of the telescope. It thus describes the tangent of the vertical angle. The distance between the telescope axis and the vernier pivot being 1, the scale on the slit is made equal to it and subdivided into 100 parts. Readings of the tangent are, therefore, made to three places of decimals. A similar apparatus is attached to the horizontal plate and gives the secants of the horizontal angles. To the horizontal plate is also attached an arc, giving horizontal tangents, for setting out curves. In this way the use of tables is obviated. Drawings of the instrument are given in the *Engineer* of December 15, 1905. The Hammer-Fennel tacheometer* is another improved instrument of great accuracy, by the aid of which slide rules or tables can be dispensed with.

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* *Trans. Inst. Min. Eng*, vol. xxvii., 1905, p. 373.

CHAPTER XIX.

SETTING-OUT.

Setting-out Railways to Mines.—Railways to mines may easily be set-out when the ground presents no great irregularities, the best line for the railway being determined by levelling from the starting-point to the mine. The line, of which a trial section shows the fewest difficulties of construction, having been selected, it is roughly marked out on the ground by strong pegs. The entire line is then carefully levelled and an accurate section drawn. From this the amount of cutting and embankment necessary may be determined. The entire line is then set out on the ground.

Two stakes are driven into the ground with their heads at the intended formation level, at distances of about 50 feet apart, near the commencement of a proposed cutting. The excavators are then able to carry on the cutting at the proper rate of inclination by a process called *boning*. This consists in ranging a line, of uniform inclination, from two points in it with T-shaped instruments, called *boning rods*. Boning rods of the same height are held vertically upon the two stakes driven into the ground, and a third rod is held at some point along the intended slope; then, if the inclination is correct, the tops of the three rods will be in line. If the third rod is too low or too high, it must be raised or lowered until it is in line with the tops of the other rods.

Ranging Curves.—Railway curves are of frequent occurrence, and even branch railways to mines, which are usually not of great length, can rarely be made without them.

A common method of setting-out a railway curve of a given radius on the ground is by means of offsets. In Fig. 133, A and G are the ends of the straight portions of the line to be connected by a curve, being the two points at which the curve falls into the straight lines. Let A C, C E, E G be the distances which it is desired that the points found in the curve shall be apart. Then measure, upon the straight line A C produced to D, the distance C D equal to C E, and join D E. This distance D E is called the *offset*, and gives a point E in the curve. Range a straight line through the points C E, and upon it lay off the distance E F equal to E G, and join F G. The point G will be the next point in the curve. Proceed in the same way until the whole extent of the curve has been set out. Let r be the radius of the curve, and d the distance A C, C E, or E G, which it is desired that the points found in the curve shall be apart, then the value of the offset is

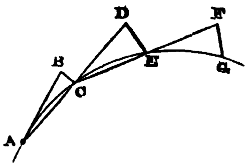

Fig. 133.

$$DE = \frac{CE \cdot AD}{2r}.$$

If C E and E G are two equal chords, the offset is

$$FG = \frac{CE \cdot CD}{r} = \frac{CE^2}{r}.$$

A B being a tangent to the curve at A, the value of the offset from the tangent is

$$BC = \frac{AC^2}{2r}.$$

The values of C D and E F will be found from the following equations:—

$$\sqrt{CE^2 - DE^2} = CD, \text{ and}$$

$$\frac{CE\,(r - DE)}{r} = EF.$$

For example.—Let $r = 15$ chains or 990 feet, and the distance $d = 1$ chain or 66 feet, the length of the first offset is $\frac{66^2}{2 \times 990} = 2{\cdot}2$ feet. The distance to be laid off upon the line A O produced to give the place for this offset is $\sqrt{66^2 - 2{\cdot}2^2} = 65{\cdot}963$ feet. Again the length of the second offset is $\frac{66 \times 65{\cdot}963}{990} = 4{\cdot}397$ feet, and the distance to be laid off upon the chord produced to give the place for this offset is $\frac{66 \times (990 - 2{\cdot}2)}{990} = 65{\cdot}85$ feet.

A rough method of setting-out curves is to extend a line from the tangential portion of the railway and measure an offset at the end of each chain along the tangent. The successive offsets in fractions of a chain should be—

$$\frac{1}{2\,r}, \frac{2^2}{2\,r}, \frac{3^2}{2\,r}, \frac{4^2}{2\,r}, \ldots \frac{n^2}{2\,r},$$

where r is the radius in chains. The length of the first offset in inches would be $\frac{792}{2\,r}$ or $\frac{396}{r}$, in which 792 represents the number of inches in a chain.

For example.—If the curve has the radius of 40 chains, the length, in inches, of the offset at the end of the first chain is 9·9. The second offset is 39·6 inches, the third 89·1 inches, and the fourth 158·4 inches.

A more rapid and more accurate method of setting-out circular curves is by means of angles at the circumference, a method first described by Rankine in 1843. It is based on the theorem (*Euclid*, III., 20) that the angle subtended by any arc of a circle at the centre of the circle is double the angle subtended by the same arc at any point in the circumference of the circle. In Fig. 134, A B is an arc of a circle, C is a point in its circumference lying beyond the arc. The angle A C B is half the angle subtended by A B at the centre of the circle. When the point at which the angle is measured lies upon the arc, as at E, it is the angle B E F = A E G that is equal to half the angle at the centre of the circle. When the point at which the angle is measured is one of the ends of the arc, as at A, it is the angle D A B that is equal to half the angle at the centre of the circle, expressed by a formula, the angle at the circumference in minutes = A C B = F E B = D A B = half the angle at the centre

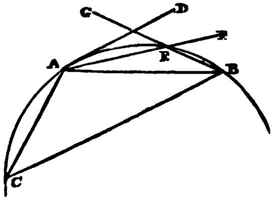

Fig. 134.

$$= 1718'{\cdot}873\,\frac{\text{length of arc}}{\text{radius of circle}}$$

in which formula, the coefficient is the value in minutes of one half of the arc that is equal to the radius.

The English practice of designating curves by their radii in chains has but few advantages, as there are no acreage calculations involved. It is preferable to express the radii in hundreds of feet, or chains of 100 feet. This method is now coming into general use. The American practice is to designate curves by the number of degrees in the angle subtended at the centre by an arc whose chord is 100 feet in length. Thus, curves are named one-degree curves, two-degree curves, etc., when the central angle subtended by 100 feet is one degree, two degrees, etc. In this method, which is one of great convenience, confusion is created by terming the centre angle "the angle of deflection." The value of this angle in degrees is 5729·6 divided by the radius in feet.

In setting-out curves by means of angles at the circumference, a transit-theodolite is set and adjusted at a tangent point, as A, and directed along the tangent to D. An angle equal to half the degree of curvature is deflected from A D towards the side on which the curve is to run. Of the two chainmen, the follower holds his end of the chain at A, and the leader, keeping the chain stretched, is directed by the observer at the instrument into line with the axis of the telescope. In this way, the position of the point E on the curve is fixed. From the line A E, the same angle is set off, the instrument remaining at the tangent point. The chainmen move forward; the follower stopping at E, and the leader moving the stretched chain around that point as centre until the other end comes into line with the axis of the telescope. A second point B on the curve is thus obtained. By continuing the process of setting off angles equal to half the degree of curvature, and causing them to subtend distances of 100 feet each, the entire curve is set-out. It is necessary that the angle formed by producing the straight portions of the line, should be known, in order to find the place on the ground from which the curve is to start. As a rule, this may be taken at once with the theodolite. If an obstacle x intervenes, a point y is selected on one tangent, from which the distance $y z$ to the other tangent may be measured. The lengths $x y$ and $x z$ are then found by solving the triangle $x y z$.

When obstacles prevent all the points from being set-out from one tangent point, the theodolite must be moved to the last point set-out, having the last angle clamped on its upper plate. The original tangent point being sighted with the vernier clamped at that angle, by setting it off a new tangential direction is obtained. By revolving the telescope, the tangent is produced in the other direction, from which tangential angles may be set-off to fix more points on the curve.

For example.—If the radius of the circle is 19 chains or 1,254 feet, and the distance required between the points in the curve 100 feet, the tangent angle to be set-off will be

$$1718{\cdot}873 \times \frac{100}{1254} = 137{\cdot}07 \text{ minutes} = 2^\circ\ 17'\ 4''.$$

The method of setting-out curves assumes that the chord of an arc is equal to the arc itself. The difference does not, however, give rise to sensible error.*

Cross-sections.—When each curve has been ranged, stakes, branded with the distance from the beginning of the line, should be driven in.

To ascertain the amount of excavation or embankment required to form the railway, cross-sections must be taken at each chain length at right angles to the longitudinal-section. The slope at which it is desirable to form a cutting or embankment depends on the nature of the ground. The usual slope is 1 foot fall in 1½ foot horizontal, or expressed by the *ratio of slope* 1½ to 1. Experience shows that dry sand will stand at an angle of 35°, dry loose shingle at 39°, and damp earth at 54°.

Driving Levels Underground.—In driving levels, it is usually necessary that a certain inclination shall be maintained. The miner must consequently be provided with suitable appliances in order to enable him to fulfil the required conditions. The best gradient is 1 in 120, as with that rise from the shaft the work performed in drawing the full load out is equal to that expended in taking the empty load in.

In metal mines, if the level has to be driven horizontal, the easier method is to conduct water into it. A dam is erected just before the working end, and the level is so driven that the water always maintains the same height. This method can, however, only be applied when no water is given off from the rock in the level, as with the slightest influx of water, the surface is disturbed and ceases to be horizontal.

The inclination of the level may be checked by means of a plumb-bob. The instrument usually employed (Fig. 135) is made of deal boards, 1¼ inches thick. The foot-piece is 6 feet in length and 4½ inches broad. The vertical piece is 3 feet in length, and

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* For accounts of the methods of setting-out curves in cases where extreme accuracy is required, the student may consult L. D. Jackson's *Aids to Survey Practice*, London, 1880, pp. 208-288; J. C. Trautwine's *Field Practice of Laying out Circular Curves for Railroads*, New York, twelfth edition, 1886; W. J. M. Rankine's *Civil Engineering*, London, twenty-first edition, 1900.

6 inches broad at the lower end, tapering upwards until, at the top, it is 4 inches broad. In addition to the plummet, there is a small spirit level fixed to the foot-piece to serve as a check. The instrument is placed on the floor of the level, and if the latter is being driven truly horizontal, the plummet will hang in the hole made in the vertical piece for its reception, and at the same time the bubble will be in the middle of its tube.

The main horse-roads in collieries should be driven with a slight inclination towards the shaft, so that water may flow from the workings to the sump. Experience has shown that an inclination of 1 in 130, or a little more than ¼ inch in the yard, gives the most advantageous effect in drawing by horse-power the loaded waggons towards the shaft, and the empty ones back. Care must be taken that this inclination is not exceeded, as, in driving levels, there is always a tendency to rise too fast. For maintaining the required inclination, a piece of board, ½ inch thick, should be screwed to the foot at the end of the instrument which is nearer the shaft.

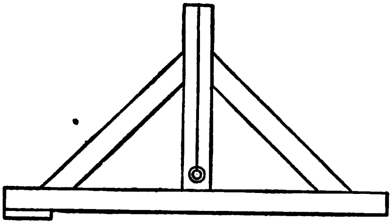

Fig. 135.

In order to test the inclination of an underground roadway with an inclination of 1 in 5, Mr. W. Wardle uses the instrument shown in Fig. 136. It is provided with two sole-pieces, the bottom of the lower one being at a distance of 1 foot from that of the upper one at one end, whilst at the other end it is brought to a feather edge.

An ingenious clinometer, invented by Colonel G. P. Evelyn (patent 1885, No. 1964), may be advantageously used for setting out levels at any inclination. It consists of a curved tube filled with water or dilute spirit, on which floats a small bubble of compressed air. Adjacent to the tube, and concentric with its outer periphery, is the graduated arc of a circle. When the air-bubble is at the zero point of that arc, the base of the stand, in which the tube is mounted, is horizontal, and any inclination from the horizontal is shown in degrees by the position of the bubble on the graduated arc. The tube is easily filled and emptied, and the size of the bubble is regulated by a screw-cap fitting over the cork.

To drive a level straight at a given bearing, plumb-lines are suspended from points in the roof previously fixed by the dial or theodolite. These lines indicate the direction in which the level has to be driven, and should be placed 30 to 60 feet apart.

Mr. J. R. Jameson has devised an adjustable portable instrument for ranging lines underground. It consists of a small bronzed metal plate with a sight vane in the centre. Above this is a swivel open triangle, that enables the plate to be turned in any direction required; and attached to it is a long metal chain, with a hook at the end for hanging to the roof. The chain works through a small adjusting plate so that the sighting plate can be raised or lowered at will. The instrument, which is made by Mr. A. G. Thornton, of Manchester, weighs 6 ounces, and is used in conjunction with one suspended cord.

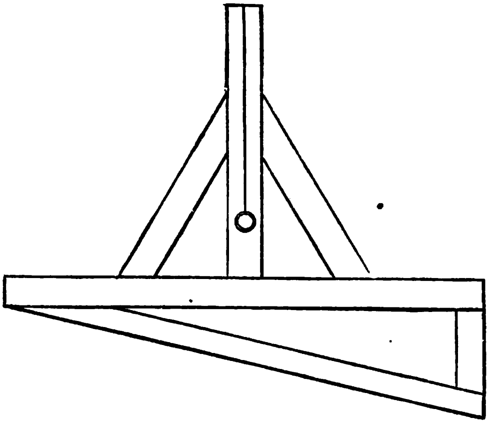

Fig. 136.

Curves for Engine Planes.—Curves may be set out underground by means of a theodolite on a short tripod, and candles or lamps instead of ranging poles.

The direction in which curves for engine planes should be set out is sometimes ascertained by making a careful survey and plan of the pillars and headings, through which it is required to drive the curve. The survey is plotted on a large scale—*e.g.* 16 feet to an inch. The curve drawn on the plan is divided into equal distances marked by points. The latter are then connected by dotted lines. By means of a protractor, the bearing of each of these lines is determined. For greater accuracy, offsets are measured at every 6 feet on each side of the lines to the sides of the curve. In this way data are obtained from which the curve may be set out.

Setting-out Tunnels.—The centre-line of the tunnel having been ranged on the surface of the ground, a series of shafts are sunk from 100 to 200 yards apart along that line. In order to transfer the ranging of the line from above to below the surface of the ground, it is necessary to have two marks, consisting of nails driven in the cross-timbers in the centre-line at the bottom of each shaft as far apart as possible, to enable the line to be prolonged from the bottom of the shaft in both directions. To determine the positions of the marks underground, a ranging-frame is erected over the shaft. It consists of three half-timbers framed as a triangle and supported at the angular point by stout props. From the frame are suspended two plumb-lines, which are ranged by a transit-instrument.

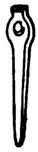

Fig. 137.

As this process cannot be satisfactorily used except in calm weather, Mr. F. W. Simms introduced the following modification:—By means of the transit-instrument, the engineer ranges two stakes in the centre-line at the surface, each being about 16 feet from the centre of the shaft, so as to be safe from disturbance while the work is in progress. To mark the exact position of the centre-line a spike (Fig. 137) is driven into the top of each stake. The hole of each spike is carefully ranged in the centre-line, a piece of white paper being held at a short distance behind it, so as to render it visible to the observer at the telescope. A string is stretched centrally across the mouth of the shaft, and its ends are passed through the holes in the spikes. It is then drawn tight and made fast. At each side of the shaft a plank is fixed at right angles to the string, and so placed that one side hangs over the shaft about 3 inches, so that a plumb-line may hang from it without coming in contact with the side of the shaft. A plumb-line being hung from each plank directly under the cord marking the centre-line, the lower ends of these plumb-lines represent two points in the centre-line at the bottom of the shaft.

The approximate ranging of the heading connecting the lower ends of the shafts is effected by means of candles, each hung from the timbering in a sort of stirrup. The upper portion of the candle-holder (Fig. 138) employed by Mr. Simms is made of thin sheet-iron with a number of holes in it. The lower portion is of iron wire, carrying a socket for the candle. By means of the rack, the latter can be raised or lowered to the proper level, and being hung by a flat plate, it is prevented from rotating.

The accurate ranging of the centre-line, when the heading has been made, is effected by stretching a string between the marks already ranged at the bottom of the shaft, and fixing, at intervals of about 40 feet, either small perforated blocks of wood carried by cross-bars, or stakes with eyed-spikes driven into their heads, so that the holes may be ranged by the string exactly in the straight line.

This method was employed by Mr. Simms for setting-out the Bletchingley and Saltwood tunnels on the South-Eastern Railway. Both these tunnels were straight from end to end, as is generally the case. Their centre lines were ranged with a transit-instrument of 30 inches focal length with an object-glass of 2¾ inches aperture. In order to command a view of every shaft, the instrument, mounted on a cast-iron stand, was set up on the highest point of ground as near the middle of the tunnel as possible, and raised above the surface by the erection of a temporary observatory. This consisted of a building of larch poles, in the centre of which was a brick pier 30 feet in height for the support of the instrument.

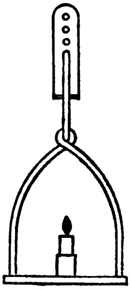
Fig 138

When the length of the tunnel is not very great, the transit-instrument and temporary observatory may be dispensed with, and the 6-inch or 5-inch transit-theodolite used with advantage. This was done in setting-out the Clifton tunnel in 1871 to 1874. This tunnel is straight, on an incline of 1 in 64. It is 1,737½ yards in length. At a distance of 276 yards from the lower end of the tunnel, where it approaches to within 140 feet of the Blackrock Cliff, a side drift was opened from the face of that cliff to the line of the tunnel. The tunnel was driven from this drift, and from two shafts sunk 998½ yards and 4·63 yards farther on.

When the tunnels are of great length, and can only be driven from the ends, the setting out is much more difficult than when shafts can be sunk along the line. The direction of the axis of the tunnel is determined by a traverse or a triangulation connecting the two ends. In very long tunnels, such as those of the Alps, traversing is not sufficiently accurate, and recourse must be had to triangulation, as was the case at St. Gothard. The St. Gothard tunnel, one of the longest railway tunnels made, is 9 miles in length. Its construction lasted from September, 1872, to February, 1880. The holing was effected on February 28, 1880, the length being 25 feet less than was expected. The error in level was 1·97 inches, and the error in alignment was 12·99 inches (Fig. 139).

The Mont Cenis tunnel was set out in the years 1857 to 1858, without triangulation, with the aid of a high observatory. The length of the tunnel was determined by triangulation, and the line of levels was carried over the mountain. The tunnel is upwards of 6 miles in length, and the junction was effected without any error horizontally, and with only a foot of divergence vertically.

The Simplon tunnel was completed in 1905. The total distance between the two portals is 21,564 yards or 12·26 miles, and the junction was effected with a lateral divergence of 0·663 foot, and a difference in level of 0·285 foot. The altitude of the highest point is 2,314 feet, being 1,474 feet lower than that of the St. Gothard, and 1,934 feet lower than that of the Mont Cenis. The gradient on the northern portion of the tunnel is 1 in 500, but on the southern portion the gradient is 1 in 142. For setting-out the tunnel recourse was had to triangulation. The network of triangles comprised 11 points, including the two terminal points of the tunnel. The highest point was on Monte Leone, 11,666 feet above sea level, and the lowest at the southern portal, 2,076 feet. The signals used had to be very solidly built. They consisted of brick pillars with cement mortar with an iron tube inserted in the axis in such a way that its top was level with the surface of the pillar. In the tube a wooden staff was placed, and over its top a conical cap of sheet zinc was firmly screwed on to the stone pillar with four iron bolts. The top edge of the tube, the point of the staff, and the apex of the cap were accurately centred. When an observation was made, the zinc cap was removed, the staff taken out, and the levelling screws of the theodolite were placed on a circle drawn in pencil on the surface of the pillar concentrically to the tube. As a check each signal was also determined by three crosses chiselled in the rock at measured distances from the signal axis. A special base line was not measured, but the triangles were connected with a side of the existing Swiss triangulation.

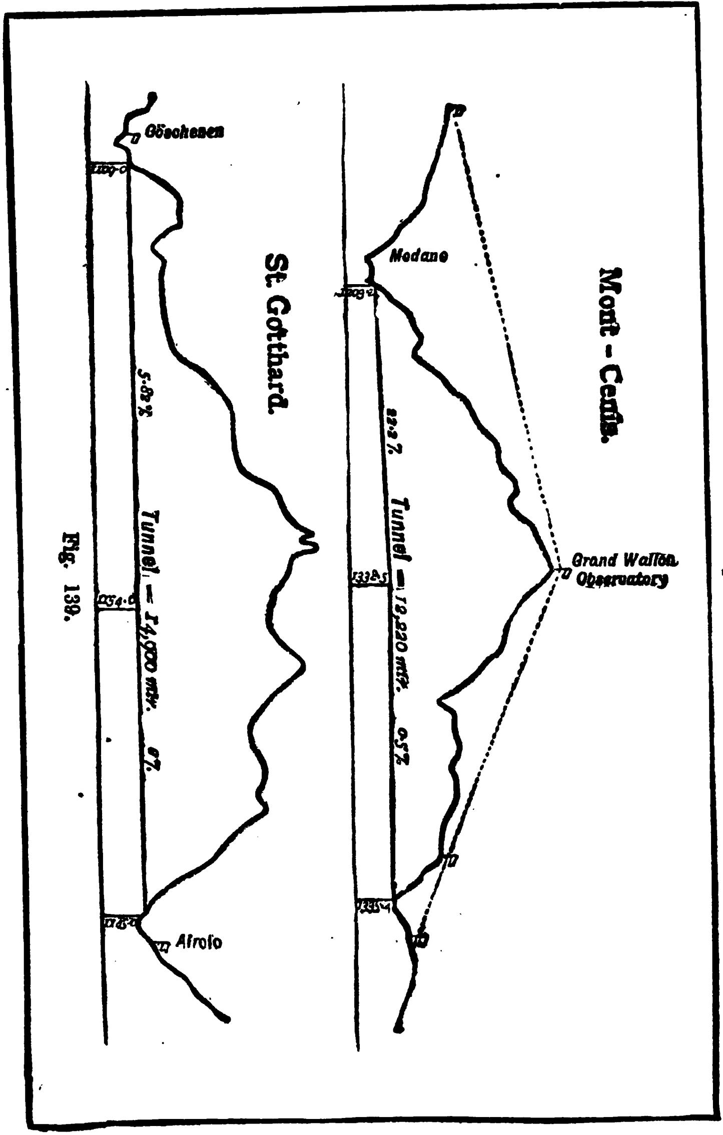
St. Gotthard.
Göschenen
1109·0
5·82%
Tunnel = 14,920 mtr.
1154·6
1%
1145·0
Airolo
Mont - Cenis.
Modane
1202·2
22·2%
Tunnel = 12,220 mtr.
1338·5
0·5%
1335·4
Grand Wallon Observatory

Fig. 139.

The coincidence of the headings on holing is affected not only by the measurement of the triangles, but also by the setting-out of the direction underground. Special precautions were, therefore, taken to ensure accuracy. In the direction of the axis of the tunnel on each side an observatory was erected from which the direction was tested once or twice a year whilst work in the tunnel was suspended. At first it was easy to sight into the tunnel from the observatory, but as the distance driven became greater an auxiliary instrument had to be employed. Heavy tripods, made entirely of iron with centring head, were used for the instrument and for the lamp sighted. The latter consists of an acetylene burner protected by a semi-cylindrical cover polished inside for reflecting the rays of light, and provided in front with an adjustable slit for sighting at. The burner is connected by a rubber tube with the generator which is suspended from a hook below the tripod head.

Remarkably accurate results in tunnel alignment were obtained in 1888 in the Croton aqueduct at New York. The points of commencement of two headings were 6,400 feet apart, the one being 270 feet and the other 353 feet below the surface. The diameter of the heading was 16·5 feet. The direction was obtained by means of two plumb-lines, 16·5 feet apart, let down each shaft. When the two headings approached each other, the final connection was made by two drills meeting in the same hole from opposite sides of the rock, and after the blast had been fired, it was found that the error in grade was 0·014 foot, and in alignment 0·09 foot.

In the construction of Division No. 6 of this aqueduct, Mr. F. W. Watkins, the engineer in charge, found that the centre-line wires were very difficult to distinguish, as the cross-hair of the telescope and the two plummet lines appear so nearly alike. He was, therefore, induced to devise an illuminated slit apparatus to replace the wires at the bottom of the tunnel. This instrument consists of two vertical strips of brass (3 inches in height) attached to separate horizontal bars moving in guides, and provided with a tangent-screw motion, by which one or both could be moved right or left and the vertical aperture between them made as small as desired. One of these instruments was screwed to a plank-bracket, close behind each plummet wire, and so placed that the farther one could be seen through the telescope in line just above the other. When these slits were adjusted, so as to be directly behind the plummet wires, the latter were removed, and lights placed behind the slits. In this way two fixed and illuminated points were substituted for the wires. The results of tests of the alignment effected in this way show that the accuracy of the surveys was very remarkable.

Taking cross-sections for measuring the areas and quantities of excavation in tunnel work is best done by measuring the irregularities of the contour of the section by angles and distances from some point in the vertical plane through the axis of the tunnel. For the Croton aqueduct tunnel, where sections had to be made every 10 feet for over 30 miles of tunnel, a convenient instrument was designed by Mr. A. Craven. This instrument, known from its yellow disc of varnished wood as the sunflower instrument, consists of a light wooden tripod with extensible legs, a shifting top, ball and socket joint, and levelling screws. A vertical brass tube slides through the socket, and carries at its top a wooden graduated disc, 18 inches in diameter. An arm revolving on a central socket traverses the face of the disc, and a wooden measuring rod, 14 feet in length, is placed on this arm, and slid out to touch the surface of the tunnel, the end of the arm at the same time indicating the angle from the vertical. The measuring rod tapers from 2 inches to ½ inch in width, and is graduated in feet and tenths from the smaller end. In order to ensure the cross-section being taken at right angles to the axis of the tunnel, the disc is provided with a small sighting tube perpendicular to its face. The measurements are recorded in the field-book, and the areas of the cross-sections are determined by calculation, or by the planimeter.

When the difficulties of the task are duly considered, it is probable that the accuracy of the work at the Hoosac tunnel has never been equalled. This tunnel passes through the Hoosac Mountain range in Massachusetts, and is 25,031 feet in length. The tunnel was driven from the two ends, and also from a shaft 1,028 feet deep, sunk in the valley between two mountains in the line of the tunnel. On the east side, the headings met at a distance of 1,563 feet from the shaft, and 11,274 feet from the eastern end, the lateral error being 0·025 foot and the vertical error being 0·23 foot at the point of junction. Proceeding westward, the tunnel extended 2,056 feet from the shaft before meeting the excavation on the western side, which was 10,138 feet from the west entrance. The holing showed that the error of alignment was 0·045 foot. The alignment in the central shaft was obtained by two plumb-bobs 25 feet apart.

Curiously enough, the oldest piece of tunnelling of which there is any written record was begun at the two ends, its construction being recorded in the oldest example of Hebrew writing known. The inscription, now known as the Siloam inscription, was discovered by some boys bathing in the Pool of Siloam, in Jerusalem, in 1880. It is cut on a tablet 27 inches square at the mouth of the tunnel, and, according to the translation of Professor Sayce, reads as follows:—

"[Behold] the excavation! Now this is the story of the tunnel: While the miners were still lifting up the pick towards each other, and while there were yet 3 cubits [to be broken], the voice of one called to his neighbour, for there was an excess in the rock on the right. They rose up—they struck on the west of the tunnel; the miners struck each to meet the other pick to pick. And there flowed the waters from their outlet to the Pool for 1,200 cubits, and [three-quarters] of a cubit was the height of the rocks over the heads of the miners."

From this inscription, it is evident that the tunnel was begun from the two ends. And this view is confirmed by the results of recent explorations. The Pool of Siloam is supplied with water from the so-called Spring of the Virgin, the only natural spring near Jerusalem, by this tunnel driven in the rock. According to Colonel Conder's survey, the tunnel is 1,708 feet long, or about 1,200 cubits of 18 inches. It does not, however, run in a straight line, and towards the centre there are two *culs-de-sac,* of which the inscription offers an explanation. We thus see that the engineering skill of the day was by no means despicable. Like the Mont Cenis tunnel, this aqueduct was begun simultaneously at the two ends, and in spite of its windings the workmen almost succeeded in meeting at the middle. They approached, indeed, so nearly to one another that the noise made by the picks of one party of miners was heard by the other, and the parting of rock was accordingly holed. This accounts for the two false cuttings now found at the centre of the tunnel, these representing the extreme points reached by the two parties before they had discovered that instead of meeting they were passing one another.

Though the inscription contains no indication of date, Professor Sayce is of opinion that the tunnel was made in the reign of Hezekiah, or possibly even in the time of Solomon.

With regard to the interpretation of the last line of the inscription that "three-quarters of a cubit was the height of the rock over the heads of the miners," it is remarkable that the difference of height of the two channels at the point of junction is just

13 inches, or close upon three-quarters of a cubit. Unfortunately, however, the text is deficient just in the place where the number occurs, and it may possibly indicate that the miners knew the thickness of the rock above them. In this case, the correct interpretation is probably 100 cubits, the average thickness of rock above the aqueduct. Several marks, evidently artificial, were discovered by Colonel Conder in the tunnel—square or triangular notches, measuring 1½ inches in width. These appear to have been used, like the peg and nail of the Cornish miner, to mark the end of a periodical survey, or else to serve as a guide in setting the contracts to the miner.

It is certainly remarkable that there should have been so slight a difference in level between the two portions of the tunnel. It would have been easy, by means of a plumb-line or a rude water-level, to preserve the level of the channel floor; but it is extraordinary that the two ends should differ by only a foot in level, considering that they were started independently.

In New South Wales, a very successful alignment was effected by Mr. T. W. Keele * in the construction of the Nepean tunnel, a conduit for supplying Sydney with water. The tunnel is 23,507 feet long, the bases at the east and west ends being 254 feet and 212 feet respectively, situated at the bottoms of precipitous limestone gorges. There were six shafts, admitting of only 12-foot bases, the depths varying from 210·5 feet to 324 feet. The length between shafts Nos. 2 and 3 was 4,341 feet, the headings meeting at a point 3,018 feet from shaft No. 2. The error in alignment was ⅝ inch, and in grade ¼ inch. The tunnel is 7½ feet high and 9½ feet wide, and is inclined at the rate of 2½ feet per mile.

The line was transferred from the surface to the bottom of the shafts by plumbing. At the shafts brick pedestals were erected, one on each side, on the centre line, and about 50 feet apart, the tops being a foot above the shaft platform. Points were then accurately established on each, and a steel wire, 0·02 inch in diameter, strained at its utmost tension from point to point across the shaft. The process of plumbing down the shaft was then proceeded with. An 8-inch transit theodolite on its centring legs was then set up in one of the headings, and the intersection of its cross-wires brought into coincidence with the line as given by the plummets. After the instrument had been adjusted to prolong the line into the heading, a hole was drilled in the roof and a wooden plug inserted; and on this the point was obtained by sighting on to a plummet lamp, of the type

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* *Min. Proc. Inst. C.E.*, vol. xcii., 1888, p. 259.

used in Pennsylvania, suspended from it. In order to give the levels in the tunnel, the value of a bench-mark at the bottom of a shaft was ascertained by measuring the calculated distance from the surface with a steel tape; and the levels were run into the headings. At intervals of 100 feet, hooks in pegs in the sides of the tunnel, and opposite to each other at right angles to the line, were so adjusted that strings stretched through them were exactly $2\frac{3}{4}$ feet above the grade. The plummet lamps, hanging from the centre-pegs in the roof, being then lowered until their lights were even with the horizontal strings, the axis of the tunnel was determined, and the miners were provided with both line and grade. All that they required to do was to place a candle at the face in line with the lights from the plummet lamps, and measure down 2 feet 9 inches to find the grade of the invert. Bench-marks were established at intervals of 500 feet, and were frequently checked.

The lengths of the headings and the results of the alignment, when the junctions were effected, were as follows:—

Name of Heading.	Length in Feet.	Error in Inches.	
		In Line.	In Grade.
Inlet. No. 5, West.	2054·0 1513·2	3	$\frac{9}{16}$
No. 5, East. No. 4, West.	935·0 1970·0	3	Nil
No. 4, East. A, West.	2468·0 425·0	$\frac{3}{8}$	$\frac{1}{16}$
A, East. No. 3, West.	496·0 1359·0	$\frac{3}{8}$	$\frac{1}{8}$
No. 3, East. No. 2, West.	1323·4 3018·0	$\frac{5}{8}$	$\frac{1}{4}$
No. 2, East. No. 1, West.	2385·0 2286·0	$\frac{3}{8}$	$\frac{1}{4}$
No. 1, East. Outlet.	1126·5 2148·0	$2\frac{3}{4}$	$\frac{1}{10}$

After the tunnel had been pierced through, daylight at one end was distinctly seen, without the aid of a telescope, from the other, 4½ miles away.*

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* On tunnelling, consult F. W. Simms' *Practical Tunnelling*, 3rd ed., revised by D. K. Clark, London, 1877; H. S. Drinker, *Tunnelling*, New York, 1878; F. Rziha, *Lehrbuch der gesammten Tunnelbaukunst*, 2 vols., Berlin, 1867-72, with the authorities there cited; and F. W. Watkins, on "Tunnel Surveying on the New Croton Aqueduct," *Trans. Amer. Soc. C.E.*, vol. xxiii., 1890, p. 17. Valuable information on the setting-out of tunnels on the Dore and Chinley Line of the Midland Railway is given by P. Rickard, *Min. Proc. Inst. C.E.*, vol. cxvi., 1894, p. 115.

CHAPTER XX.

MINE-SURVEYING PROBLEMS.

Determination of the Direction and Inclination of a Mineral Deposit.—Problems relating to the working of mines may be solved graphically or numerically. Graphic solutions are the most simple, but the accuracy of the results is dependent on that of the plans on which they are based. Most problems are therefore more conveniently solved by the ordinary methods of descriptive geometry.

To determine the strike and dip of a vein that has been opened by a level driven along it, a simple method is to select two points in the axis of the level, either on the floor or on the roof. At these two points two vertical props are set up, when the bearing of a horizontal string connecting the two props will be the strike of the vein. Instead of the stretched string, a rod may be held horizontally.

The strike being determined, the direction of the dip may be determined by setting off a line at right angles to the strike. The dip may be measured with a clinometer.

A convenient instrument for determining the dip of mineral deposits is the so-called *gradometer*, invented by Mr. W. Fairley. It consists essentially of a 9-inch or 4-inch scale made to move up and down a vertical bar. When the lower edge of the scale is placed on the plane of which the dip is to be determined, and is shown to be level by the spirit-level on the upper edge, the plane is horizontal. When the plane is inclined, a slide, like that of the slide-rule, marked on one side in degrees and on the other in inches per yard, is taken out and passed through a slit at right angles to the longitudinal axis of the scale. For measuring dips above 45°, a second slide is provided. The gradometer is of less weight than a clinometer of the same length, and can be read with greater facility.

If the strike of a deposit is known, its dip may be calculated. Thus if a line A E, Fig. 140, is drawn on the plane of the deposit

A B C D, and if through the point A a horizontal plane A F passes, then A B, the line of intersection of the two planes, is the line of strike of the deposit. From any point G on the inclined line A E, let fall a perpendicular G H to the horizontal plane A F, and in the latter draw a horizontal line A J, which is the line of strike of the inclined line A E. The horizontal angle B A J is the difference in bearing between the line of strike of the deposit and that of the inclined line; whilst the angle G A H in the vertical plane E A J represents the dip of the inclined line A E. Let fall in the horizontal plane A F from the point H a perpendicular line H K to the line of strike A B, and join G K. Then G K is the line of dip of the deposit A B C D, and the angle G K H in the vertical plane G H K represents the angle of the dip of the deposit.

If the strike A B of the deposit is expressed by c, and the angle

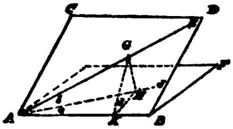

Fig. 140.

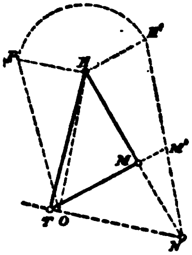

Fig. 141.

B A J $= e$, and the strike of the inclined line $= a$, then $e = c - a$. In the right-angled plane triangles A G H and A H K,

$$\begin{aligned} \mathrm{G\,H} &= \mathrm{A\,G} \sin b, \text{ and} \\ \mathrm{H\,K} &= \mathrm{A\,G} \cos b \sin e. \end{aligned}$$

Then from the triangle G H K, the value of the required angle of dip may be found from the formula—

$$\tan \mathrm{G\,K\,H} = \frac{\mathrm{G\,H}}{\mathrm{H\,K}} = \frac{\mathrm{A\,G} \sin b}{\mathrm{A\,G} \cos b \,.\, \sin e} = \frac{\tan b}{\sin e}.$$

Conversely if the angle of dip d is known, the strike may be found from the formula $\sin e = \tan b \,.\, \mathrm{cotan}\, d$.

For example.—1. What is the dip of a seam coursing 127° 30′, if a diagonal heading driven in the seam has a dip of 4°, and courses 90° or due east and west? The angle e is $= 127° 30' - 90° 00' = 37° 30'$. The dip d is then found from the equation

$$\tan d = \frac{\tan 4°}{\sin 37° 30'}.$$

Employing logarithms, this gives

$$\begin{array}{ll} \text{L} \tan 4° & = 8{\cdot}8446437 \\ \text{L} \sin 37° 30' & = 9{\cdot}7844471 \\ \hline \text{L} \tan d & = 9{\cdot}0601966 \end{array}$$

Thus $d = 6° 33' 10''$.

2. *Example.*—Determine the strike of a seam dipping 8°, in which a diagonal heading is driven, dipping 5° and coursing 60°. In this case

$$\sin e = \frac{\tan 5°}{\tan 8°}.$$

Employing logarithms, this gives

$$\begin{array}{ll} \text{L} \tan 5° & = 8{\cdot}9419518 \\ \text{L} \tan 8° & = 9{\cdot}1478025 \\ \hline \text{L} \sin e & = 9{\cdot}7941493 \end{array}$$

Therefore $e = 38° 30'$.

The strike c required is found from the equation $c = e + a$, thus

$$c = 38° 30' + 60° 00' = 98° 30'.$$

The strike and dip of a seam may be determined if three points in it are given. Thus if three bore-holes, not in a straight line, have been sunk to the floor of a seam, as shown in the plan, Fig. 141, H M T, the problem is solved as follows:—Measure the depths of the three bore-holes from the same assumed horizontal plane at the surface. In this case, T represents the deepest, and H the highest point of the deposit. Imagine perpendiculars to be erected to H M at the points H and M, and on them laid off the heights H H′ and M M′, representing the heights that the floor of the seam at the bore-holes H and M is above the floor at the bore-hole T. In this way, H′ M′ represents the line of inclination of the seam between H and M. That line is produced until it cuts the line H M produced at N. Thus a point in the seam is determined, which is situated at the same level as the bottom of the bore-hole T, and T N is the line of strike of the seam.

The line H N is found from the similar right-angled triangles H H′ N and M M′ N, to be equal to

$$\mathrm{H\,N} = \frac{\mathrm{H\,H'} \cdot \mathrm{H\,M}}{\mathrm{H\,H'} - \mathrm{M\,M'}}. \quad . \quad . \quad . \quad (1)$$

From the bore-holes, the strike of H T and the angle N H T are known, and as H N is found from equation 1, in the triangle H N T there are two sides and the included angle known, consequently

$$\mathrm{H\,N} + \mathrm{H\,T} : \mathrm{H\,N} - \mathrm{H\,T} = \tan \tfrac{1}{2}(\mathrm{T} + \mathrm{N}) : \tan \tfrac{1}{2}(\mathrm{T} - \mathrm{N}). \quad (2)$$

From this, the angles T and N are found, as half their sum is known. From the given strike H T and the angle T, the strike of the line T N may be deduced.

In order to determine the dip of the deposit, imagine a line H O drawn from H perpendicular to the line of strike T N, then in the right-angled triangle H O T, $\frac{\mathrm{H\,O}}{\mathrm{H\,T}} = \sin \mathrm{T}$, whence it follows that H O = H T sin T.

At the point H erect a line perpendicular to H O, and along it lay off the height H P, being the height which the floor of the seam in the bore-hole H is above that in the bore-hole T. Then the line obtained O P is the true line of dip, and the angle H O P represents the angle of dip of the deposit. Thus $\tan \mathrm{H\,O\,P} = \frac{\mathrm{H\,P}}{\mathrm{H\,O}}$, or, by substitution, $\tan \mathrm{H\,O\,P} = \frac{\mathrm{H\,P}}{\mathrm{H\,T} \sin \mathrm{T}}$.

Expressed by general formulæ,

$$\tan \mathrm{S} = \frac{d'}{a \sin \mathrm{V}}, \text{ and}$$

$$\tan \mathrm{V} = \frac{\frac{d\,a'}{d'} \sin \mathrm{W}}{a - \frac{d\,a'}{d'} \cos \mathrm{W}},$$

in which S is the angle of dip of the bed, V the angle between the strike of the bed and M H, a the distance from M to H, a' the distance from M to T, W the angle in a horizontal plane between M H and M T, d the difference of the depths of the bore-holes M and H, and d' the difference of the depths of M and T.

For example.—In Fig. 141, H T = 150 yards, H M = 112 yards, and M T = 100 yards, measured horizontally. The angle M H T = 41° 48′ 37″. T is the deepest bore-hole, and the floor of the seam in the bore-hole M is 32 yards, and in the bore-hole H 73 yards higher than in the bore-hole T. It is required to determine the strike and dip of the seam, when T H courses 172° 30′.

From the first equation given,

$$\text{H N} = \frac{73 \times 112}{73 - 32} = 199{\cdot}41 \text{ yards.}$$

Now, $T + N = 180° - 41°\ 48'\ 37'' = 138°\ 11'\ 23''$, and half $T + N = 69°\ 5'\ 41{\cdot}5''$. From the second equation

$$\tan \frac{T - N}{2} = \frac{199{\cdot}41 - 150}{199{\cdot}41 + 150} \,.\, \tan 69°\ 5'\ 41{\cdot}5''$$

$$= \frac{49{\cdot}41}{349{\cdot}41} \,.\, \tan 69°\ 5'\ 41{\cdot}5''$$

From this, half $T - N$ is found by logarithms to be 20° 18′ 55″. Half $T + N$ being 69° 5′ 41·5″, T is equal to 89° 24′ 36·5″, and N is equal to 48° 46′ 46·5″.

As the strike of T H is 172° 30′, and as T N lies to the right of T H, the strike of the latter is

$$(172°\ 30' + 89°\ 24'\ 36{\cdot}5'') - 180° = 81°\ 54'\ 36{\cdot}5''.$$

The angle of dip H O P is found from the equation

$$\tan \text{H O P} = \frac{73}{150 \,.\, \sin 89°\ 24'\ 36{\cdot}5''}.$$

By the aid of logarithms, the angle H O P is found to be 25° 57′ 7″.

The strike of the seam, as found above, can be set out at the surface in the usual way.

Determination of a Point at the Surface directly above one Underground.—If it is required to determine the position of the end of a level, it will be found advisable to calculate it trigonometrically instead of by plotting the traverse at the surface.

The rectangular co-ordinates of the underground-survey are calculated, and the distance and bearing of the end from the shaft found from the formulæ:

$$\tan \text{ of bearing} = \frac{\text{departure}}{\text{latitude}}, \text{ and}$$

$$\text{distance} = \text{latitude} \times \sec \text{ of bearing.}$$

For example.—In order to calculate the bearing and distance of the end of the level from the centre of the shaft in the survey of the Work and Rest mine, the record of which is given on p. 87, the latitudes and departures must first be calculated, with the following results:—

WORK AND REST MINE. REDUCED SURVEY NOTES.

No.	Distance.	Bearing.	Latitude.		Departure.	
			N.	S.	E.	W.
	Feet.					
A	74·50	N. 0° 15′ W.	74·49	..	..	0·32
B	82·83	N. 14° 00′ W.	80·37	..	..	20·03
C	63·00	N. 27° 39′ W.	55·80	..	..	29·23
D	30·16	N. 84° 57′ W.	2·65	..	..	30·04
E	23·75	S. 74° 06′ W.	..	6·50	..	22·84
F	192·00	N. 67° 45′ W.	72·70	..	..	177·70
G	96·50	N. 88° 00′ W.	3·36	..	..	96·44
H	34·00	S. 84° 06′ W.	..	3·49	..	33·82
J	23·75	S. 52° 00′ W.	..	14·62	..	18·71
..	..	..	289·37	24·61	..	429·13

The total latitude is 289·37 − 24·61 = 264·76 feet, and the total departure is 429·13 feet. The distance from the shaft to the station-point J at the end of the level is found from the formulæ:

$$\text{tan of bearing} = \frac{429 \cdot 13}{264 \cdot 76}, \text{ and}$$

$$\text{distance} = 264 \cdot 76 \text{ sec of bearing.}$$

The calculations are performed most quickly by means of logarithms, thus—

$$\begin{array}{lcl}
\log 429 \cdot 13 & = & 2 \cdot 632588 \\
\log 264 \cdot 76 & = & 2 \cdot 422852 \\
\hline
 & 10 + & 0 \cdot 209736 = \text{L tan } 58^\circ\, 20' \\
\text{L sec } 58^\circ\, 20' & = & 10 \cdot 2798601 \\
\log 264 \cdot 76 & = & 2 \cdot 422852 \\
\hline
 & & 12 \cdot 7027121 - 10 = \log 504 \cdot 32
\end{array}$$

To determine the position of the point at the surface corresponding to the end underground, it is merely necessary to set-out from the shaft a horizontal distance of 504·32 feet at a bearing of N. 58° 20′ W.

This problem is of great importance for the determination of the position of the underground workings in reference to the boundaries of the concession or royalty.

Holing from one Excavation to another.—The usual problem relative to holing consists in determining the length and direction of the axis of a gallery joining two given points. The problem may be solved graphically or numerically. In the former case the plans employed must be rigorously exact. In the numerical method, the length and bearing are deduced from the co-ordinates of the end points.

For example.—In the survey between the Speedwell and Netherthorpe shafts at Staveley, of which the record is given on p. 164, the latitudes and departures of the 15 drafts underground from the Speedwell downcast shaft to the face of the main ventilating draft, intended to hole into Netherthorpe shaft, were calculated with the following results:—

REDUCED SURVEY NOTES.

No.	Bearing.	Distance.	Latitude.		Departure.	
		Links.	N.	S.	E.	W.
A	N. 34° 24′ W.	13½	11·14	..	..	7·63
B	N. 58° 35′ E.	639	333·08	..	545·32	..
C	N. 45° 41′ E.	274	191·42	..	196·04	..
D	N. 37° 29′ E.	130	103·16	..	79·11	..
E	N. 8° 40′ W.	127	125·55	..	..	19·13
F	N. 15° 02′ E.	405	391·14	..	105·05	..
G	N. 17° 57′ E.	206	195·97	..	63·48	..
H	N. 11° 35′ E.	158	154·78	..	31·72	..
J	N. 35° 37′ W.	73	59·34	..	..	42·51
K	N. 18° 20′ E.	260	246·80	..	81·78	..
L	N. 18° 14′ E.	470	446·40	..	147·05	..
M	N. 69° 42′ E.	384	133·22	..	360·15	..
N	S. 27° 45′ E.	63	..	55·75	29·33	..
O	N. 69° 32′ E.	73	25·52	..	68·39	..
P	N. 71° 57′ E.	78	24·17	..	74·16	..
..	..	..	2441·69	55·75	1781·58	69·27

The total latitude amounts to 2441·69 — 55·75 = 2385·94 links, and the total departure 1781·58 — 69·27 = 1712·31 links.

The direct bearing and distance measured at the surface from the Speedwell downcast shaft to centre of Netherthorpe shaft, intended upcast, were N. 37° 02′ E., 3113 links, representing 2485·06 links north latitude, and 1874·89 links east departure.

The positions from Speedwell shaft, in terms of latitude and departure, were consequently as follows :—

	N. Latitude.	E. Departure.
Netherthorpe shaft, . . .	2485·06	1874·90
Face of heading, . . .	2385·94	1712·31
	99·12	162·59

Now, tan of bearing = departure ÷ latitude, and distance = latitude × sec of bearing, therefore the distance to be holed is found as follows :—

$$\begin{array}{lll} \text{log departure} = \text{log } 162{\cdot}59 & = & 2{\cdot}211093 \\ \text{log latitude} \;\; = \text{log } \;\; 99{\cdot}12 & = & 1{\cdot}996161 \\ \hline \text{L tan of bearing} & = & 10 + 0{\cdot}214932 \end{array}$$

The bearing is therefore N. 58° 38′ E.

$$\begin{array}{lll} \text{log latitude} \;\; = \text{log } 99{\cdot}12 & = & 1{\cdot}996161 \\ \text{L sec } 58^\circ\ 38' & = & 10{\cdot}283568 \\ \hline \text{log distance} & = & 12{\cdot}279729 - 10 \end{array}$$

The distance is therefore 190·43 links.

Having thus calculated the bearing and horizontal distance from the face of the heading to the intended upcast shaft, Mr. Howard determined to drive direct into the shaft, and the drift was accordingly set-out at the calculated bearing and distance. His survey and calculations were proved by the holing to be absolutely correct.

If it is required to determine the inclination and distance of the axis of the heading uniting the two given points, and the co-ordinates of those two points referred to three axes of rectangular co-ordinates are $x\,y\,z$ and $x'\,y'\,z'$ respectively, the distance d, the bearing β, and the inclination α, may be found from the formulæ—

$$d = \sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}$$

$$\tan\beta = -\frac{x-x'}{y-y'},$$

$$\sin\alpha = \frac{z-z'}{\sqrt{(x-x')^2 + (y-y')^2 + (z-z')^2}}.$$

Attention must be paid to the signs of the co-ordinates, which always indicate the position in space of the axis considered.

A remarkable example of successful holing is afforded by the Ernst-August adit level in the Harz. This great adit, one of the longest in the world, was commenced in 1850 and completed on 22nd July, 1864; it has a total length of 25,956 metres. It was driven from the bearings and distances calculated from the results of a survey made with extreme accuracy by means of the theodolite and spirit-level from a number of points. The results of the holings were as follows:—

ERNST-AUGUST ADIT LEVEL.

	Length Surveyed.	Error on Holing.	
		In Direction.	In Level.
	Fathoms.	Inches.	Inches.
1. Holing in Regenbogen mine, .	310	0·2	0·15
2. Holing between the mouth of the adit at Gittelde, and the Fahlenberg shaft, ...	880	0·3	0·40
3. Holing between the Meding shaft and the George shaft, . .	2,700	1·5	0·40
4. Holing between the Hülfe Gottes shaft and the mouth, . .	2,760	1·0	0·23
5. Holing between the George shaft and the Knesebeck shaft, .	1,580	1·5	0·60
6. Holing between the Knesebeck shaft and the Hülfe Gottes shaft,	1,430	1·1	0·14
7. Holing between the Schreibfeld shaft and the Haus Sachsen shaft, ...	1,890	1·5	0·37
8. Holing between the Meding shaft and the Ernst-August shaft, .	3,960	1·2	0·09
9. Holing between the Ernst-August shaft and the Haus Sachsen shaft, ...	1,190	0·7	0·06

To drive a tunnel through a hill, the line of the tunnel is set out over the hill, and carefully levelled from the commencement at the foot of the hill. When it is thought that the level of the starting-point has been reached, or, in other words, when the rises are equal to the falls, an assumed mark is placed, and the levels accurately calculated. The assumed mark is then moved up or down the height by which the rises and falls differ, to give the exact position of the floor of the tunnel on the farther side of the hill.

If the levelling is effected by the theodolite instead of by the spirit level, the total of the calculated bases of the various drafts gives the length of the tunnel.

Sinking Shafts from Several Levels.—Similar problems to those relating to galleries are presented by shafts which have to be sunk from several levels. If the shaft to be sunk is near an existing shaft, the problem is comparatively simple, as it is then merely necessary to drive headings from that shaft at different levels until their ends reach the axis of the shaft to be sunk.

The conditions are not always so favourable; the shaft to be sunk may be at a considerable distance from any existing shaft. In such a case, points are selected at each level of the mine-workings, as near as possible to the shaft to be sunk. From these points headings are driven to the axis of the shaft. The length and direction of these headings may be calculated from surveys made at the various levels of the mine. It is, of course, necessary that the surveys shall be made with extreme accuracy with the theodolite.

This method was employed in the Harz for sinking the Kōnigin Marie shaft, the first perpendicular shaft sunk in that district. In 1851 it was decided by the Government authorities to drive a deep water-level at a depth of 120½ fathoms under the Ernst-August deep adit, by which the mines of the Upper Harz were then drained. The new deep water-level was intended to serve as a great common water-reservoir for the mines of the district. From this level, which is 324 fathoms below the surface, and 116 feet below sea-level, the water is raised to the Ernst-August adit. For the reception of the engine for raising the water, it was decided to sink a new perpendicular shaft, the Kōnigin Marie shaft, which should also be utilised for raising the ore from several mines.

In order to expedite as far as possible this important work, the shaft had to be sunk from several levels. It was sunk from the surface to the deep George adit, a depth of 146 fathoms, and at the same time commenced at a level 202 fathoms below the surface, and at another 270 fathoms below the surface.

Careful surveys having been made at each level, the shaft was set-out from the points obtained from the calculated co-ordinates. The different holings were successfully effected in 1866.

The accuracy of the work was then tested by suspending a plumb-line in the shaft, and determining the position of the shaft at the three levels. The plumb-line at the surface was exactly in the centre of the hoisting compartment of the shaft, at a distance of 40 inches from each of the long sides, and 70 inches from each of the short sides.

Designating the shaft as A B C D, the distance of the plumb-line from the sides at the different levels was as follows:—

	AB Inches.	CD Inches.	AC Inches.	BD Inches.
At the surface, . . .	40·0	40·0	70·0	70·0
At the 146-fathom level, .	41·5	38·5	71·0	69·0
At the 202-fathom level, .	42·6	37·4	70·0	70·0
At the 270-fathom level, .	40·8	39·2	68·6	71·4

From these results it follows that the deviation of the shaft from the vertical was as follows:—

	Short Sides. Inches.	Long Sides. Inches.
At the 146-fathom level, ...	1·0	1·5
At the 202-fathom level, ...	0·0	2·6
At the 270-fathom level, ...	1·4	0·8

Thus, the Königin Marie shaft presents a brilliant illustration of accurate mine-surveying.

The Cubical Contents of a Mine-Reservoir may easily be determined by the aid of a levelling-instrument. The cubical content must be calculated so as to ascertain the quantity of water which the proposed reservoir will hold. In shape, a mine-reservoir resembles most closely a truncated pyramid. It is, therefore, supposed to be cut, at given vertical distances, parallel to the surface of the water. The cubical content of the reservoir is then determined from the area of these horizontal sections and their vertical distance apart.

When a suitable site for the reservoir has been selected, and the height of the dam fixed, the highest level (1, Fig. 142) of the water is marked by a stake fixed into the dam. The water-line of the reservoir is then determined by finding with the spirit-level a number of points lying in the level of 1. All these points are then marked by numbered stakes. Some 2 to 3 yards vertically below the first stake, a second stake is fixed into the dam. The contour of the reservoir at this level is then determined by the spirit-level, and marked by numbered stakes. In a similar way, contours of the reservoir at lower water-levels are determined and marked out. The contours marked out by the numbered stakes are then surveyed by means of the dial, the prismatic compass, or the plane table, and laid down on a plan to a large scale. From this plan, the areas, the cubical content of the reservoir is calculated by means of the formula $V = \frac{1}{3} h (B + \sqrt{B b} + b)$, where h is the vertical height and B, b the area of the ends.

For example.—In the mine-reservoir, shown in Fig. 142, five horizontal sections were determined at vertical distances of 1·000, 1·050, 1·000, and 0·875 fathoms apart. The vertical distance from the fifth and last section to the bottom of the reservoir was 0·375 fathom. Each of the five water-levels were distinguished by numbered stakes, so marked that all belonging to one section had the same number. The five horizontal sections were then surveyed with the compass, and plotted on a suitable scale (1 : 1,000). The cubical content was then found to be 41814·13 cubic fathoms as shown in the following table:—

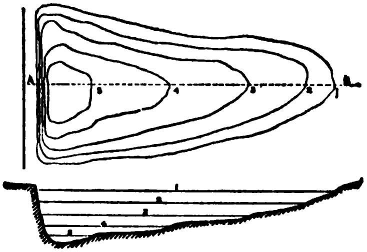

Fig. 142.

CUBICAL CONTENT OF A MINE-RESERVOIR.

Level.	Area.	Vertical Distance of Levels Apart.	Cubical Content.
	Square Fathoms.	Fathoms.	Cubic Fathoms.
1	21843·31	1·000	18931·11
2	16161·29	1·050	13362·90
3	9577·30	1·000	6825·46
4	4404·34	0·875	2500·50
5	1553·25	0·375	194·16
Bottom.	0·00	..	..
..	..	..	41814·13

The cubical content of a dump-heap is found in a similar manner.

Determination of the Strike and Dip of the Line of Intersection of Two Veins.—It is important to determine the position of this line, as it is frequently found to be a line near or along which a run of rich deposit is likely to be met with. It is also of value in solving problems relating to the dislocations of veins. Rules for determining by means of spherical trigonometry the strike of the line of intersection are given in the treatises on mine-surveying by Von Oppel (1749), Kästner (1775), and Lempe (1782). The simplest trigonometrical solution to the problem is that given by A. Rhodius.*

The problem may be solved by construction. Let *a b′* and *b″ c* (Fig. 143) be the lines of strike, at a given level, of the two lodes dipping at angles of α and α'. In order to determine the line of intersection, the perpendiculars *i k* and *l m* are let fall in the direction of the dip of the lodes, and made the bases of right-angled triangles, the hypothenuses of which are inclined at angles of α and α' respectively, the perpendicular (*h*) being the same in both cases. The lines *k n* and *m o* are then drawn parallel to *a b′* and *b″ c*, and continued until they intersect in the point *e*. Then *e* is a point of intersection of the two lodes at a level which is deeper than the point of intersection *b*, by a distance *h*, and consequently *b e* is the line of intersection of the two lodes. The strike of this line can be measured with the protractor.

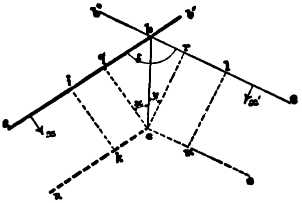

Fig. 143.

By constructing a right-angled triangle with its base equal to the line of intersection, *b e*, and its perpendicular equal to *h*, then the angle at *e* represents the angle of inclination or dip of the line of intersection. This angle may be measured with the protractor.

The preceding construction is generally to be recommended. The problem may, however, be solved by means of plane trigonometry. The following is the solution given by Rhodius:—If *b e*, as in the first solution, represents the line of intersection of the two veins *a b′* and *b″ c*, then *e q* and *e r*, lines parallel to *i k* and *l m*, are lines at right angles to the strike of the veins. The angles which *e q* and *e r* form with the line of strike *b e* of the line of intersection being indicated by x and y respectively, the following equations are obtained :—

---

* *Preuss. Ztschr.*, vol. xiv., 1866, p. 119.

$$e\,q = h \operatorname{cotan} \alpha\,;\quad e\,r = h \operatorname{cotan} \alpha', \qquad . \quad . \quad (1)$$

$$e\,q = b\,e \cdot \cos x\,;\quad e\,r = b\,e \cdot \cos y, \qquad . \quad . \quad (2)$$

$$\therefore \frac{e\,q}{e\,r} = \frac{\operatorname{cotan} \alpha}{\operatorname{cotan} \alpha'} = \frac{\cos x}{\cos y}, \qquad . \quad . \quad . \quad (3 \text{ and } 4)$$

$$\frac{\operatorname{cotan} \alpha + \operatorname{cotan} \alpha'}{\operatorname{cotan} \alpha'} = \frac{\cos x + \cos y}{\cos y}, \qquad . \quad . \quad . \quad (5)$$

and

$$\frac{\operatorname{cotan} \alpha - \operatorname{cotan} \alpha'}{\operatorname{cotan} \alpha'} = \frac{\cos x - \cos y}{\cos y}, \qquad . \quad . \quad . \quad (6)$$

$$\therefore \frac{\operatorname{cotan} \alpha + \operatorname{cotan} \alpha'}{\operatorname{cotan} \alpha - \operatorname{cotan} \alpha'} = \frac{\cos x + \cos y}{\cos x - \cos y}. \qquad . \quad . \quad . \quad (7)$$

But

$$\frac{\operatorname{cotan} \alpha + \operatorname{cotan} \alpha'}{\operatorname{cotan} \alpha - \operatorname{cotan} \alpha'} = \frac{\cos \alpha \cdot \sin \alpha' + \sin \alpha \cos \alpha'}{\cos \alpha \cdot \sin \alpha' - \sin \alpha \cos \alpha'}$$

$$= \frac{\sin (\alpha' + \alpha)}{\sin (\alpha' - \alpha)}.$$

Substituting $u + v$ for x and $u - v$ for y, so that $u =$ half $x + y$ and $v =$ half $x - y$, the equation 7 becomes

$$\frac{\sin (\alpha' + \alpha)}{\sin (\alpha' - \alpha)} = -\frac{\cos u \cos v}{\sin u \sin v}$$

$$= - \operatorname{cotan} \tfrac{1}{2} (x + y) \cdot \operatorname{cotan} \tfrac{1}{2} (x - y).$$

$$\therefore \operatorname{cotan} \tfrac{1}{2} (x - y) = \frac{\sin (\alpha + \alpha')}{\sin (\alpha - \alpha')} \tan \tfrac{1}{2} (x + y)$$

$$= \frac{\sin (\alpha + \alpha')}{\sin (\alpha - \alpha')} \operatorname{cotan} \tfrac{1}{2} \delta. \qquad . \quad (8)$$

In this, δ represents the value of the angle $a\,b\,c$, included by the lines of strike of the two lodes, so that $\frac{1}{2}\,\delta = 90° - \frac{1}{2}(x + y)$, and $\frac{1}{2}(x + y) = 90° - \frac{1}{2}\,\delta$. The angle δ is known, and x and y are found from these two equations.

The angle of dip ψ of the line of intersection is calculated in the following way :—$h = b\,e \tan \psi$, therefore,

$$\tan \psi = \frac{h}{b\,e} = \frac{h \cdot \cos x}{e\,q} = \frac{h \cos y}{e\,r}$$

$$= \frac{\cos x}{\text{cotan}\,\alpha} = \frac{\cos y}{\text{cotan}\,\alpha'}. \quad . \quad . \quad . \quad (9)$$

In order to employ this formula, the value of the angle x or y must first have been determined. The angle of dip is found more conveniently from the formula—

$$\tan \psi = 2\,\frac{\sin \alpha \sin \alpha'}{\sin(\alpha + \alpha')} \cdot \sin \tfrac{1}{2}\,\delta \cos \tfrac{1}{2}\,(x - y).$$

For example.—The strike of a lode is 101° 15′, and its dip 80° towards south; the strike of a second lode is 170° 37½′, and its dip 75° towards west; required the strike and the dip of the line of intersection of the two lodes.

By applying the formulæ given, the former will be found to be 62° 27½′, and the latter 74° 15′ 26″.

The Search for Dislocated Lodes.—In following a lode, it frequently happens that a cross-course is met, and, after driving through it, the lode is not to be found on the other side. In such cases it is said to be dislocated or *heaved*. The two intersecting veins seldom form an intersection at right angles; more commonly one is inclined to the other. In Cornwall, of 272 cases of intersection, recorded by Mr. W. S. Henwood,* 22·7 per cent. were intersected but not heaved, 26·2 per cent. were found by driving to the left hand, and 51·1 per cent. to the right hand; 63·5 per cent. were found by driving on the side of the greater angle and 12·9 on the side of the smaller angle. The average distance of dislocation was 16·4 feet.

The first clear views on the subject were put forward in 1810 by Schmidt, who stated that dislocations were to be explained by a sinking of the hanging-wall of the dislocator. Schmidt's rule, as modified by v. Carnall, is as follows :—

If the dislocator is struck on its hanging-wall, it must be passed through, and the driving continued in the hanging-wall of the dislocated lode. If the foot-wall of the dislocator is struck, it must be passed through, and the driving continued in the foot-wall of the dislocated lode. For obtuse angles of dislocation, the rule is reversed. The angle of dislocation is the angle formed by the line of intersection of the two veins, and that portion of the line of strike of the dislocator which enters into the foot-wall of the lode.

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* *Trans. R. Geol. Soc., Cornwall,* vol. v., 1843.

On Schmidt's theory, Zimmermann in 1828 based his rule, which is more convenient to use, as it makes no exception of the obtuse angle. His construction is as follows:—

At the point D (or E), Fig. 144, in which the dislocator A is cut, erect, on the line of strike and towards the inside of the dislocator, a perpendicular line D L (E L′) lying in a horizontal plane. Determine the position of the line M N (M′ N′) in which the planes of the dislocator and of the lode intersect. Prolong the line tó N (M′) towards the opposite selvage making it D N (E M′). Observe to which side the perpendicular D L (E L′) deviates from the line of intersection when it is directed towards the opposite selvage, and after passing through the dislocator, seek the dislocated portion of the lode on the side towards which the perpendicular D L (E L′) falls.

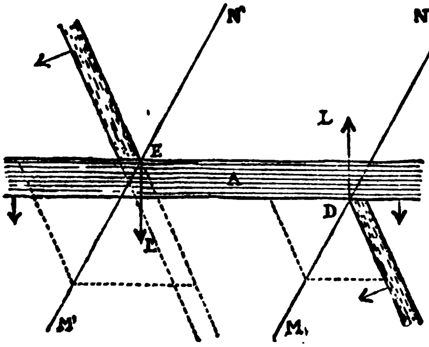

Fig. 144.

The construction is very simple. The line of intersection of the lode and the dislocator is determined by the method described. It is then merely necessary to erect a perpendicular at the point D (or E). If the line of intersection is to be determined by plane trigonometry, formula 8 is employed.

For example.—On driving along a lode, *d c*, from *d* towards *c*, Fig. 145, it is found that the lode ends at *c*, having been dislocated by a fissure *a b*. The fissure has a strike β of 118° $7\frac{1}{2}'$, and a dip α' of 55° towards the south-west, and the lode has a strike β of 150°, and a dip α of 82° 30′ towards the north-east.

The first problem is to determine the line of intersection of the two veins. The point of intersection *i* being found by the process previously described, *c i* represents the strike of the line of intersection. By erecting a perpendicular *c k* at the point *c*, it is evident that the lost vein *l m* will be found, after the dislocator has been passed through, by driving from *c* in the direction *c b*.

If the line of intersection is to be determined by means of plane trigonometry, by employing formula 8, the required line of intersection will be found to have a strike of 145° 6′ 23″.

If recourse is had to spherical trigonometry, the calculations are more simple. With *c* as the centre of a sphere, the spherical triangle A B C is described, in which the side A B ($= \varphi = \beta - \beta'$) is in the horizontal plane A *c* B, A C is in the plane of the fissure *a b*, and B C in the plane of the lode *c d*. Again, *c* D is the horizontal projection of the line of intersection S *c* C, and C D an arc perpendicular to A B, and from the two right-angled triangles A C D and B C D,

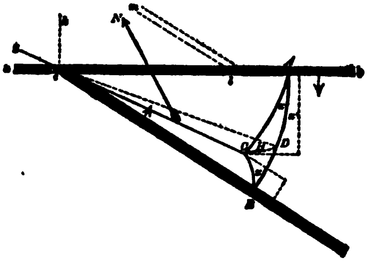

Fig. 145.

$$(1)\quad \tan y = \sin x \cdot \tan \alpha', \text{ and}$$
$$(2)\quad \tan y = \sin (\varphi - x) \cdot \tan \alpha.$$

From these two equations, it is found that

$$\operatorname{cotan} x = \frac{\tan \alpha'}{\tan \alpha \cdot \sin \varphi} + \operatorname{cotan} \varphi.$$

Numerical values being substituted,

$$\operatorname{cotan} x = \frac{\tan 55^\circ}{\tan 82^\circ\ 30' \cdot \sin 31^\circ\ 52\tfrac{1}{2}'} + \operatorname{cotan} 31^\circ\ 52\tfrac{1}{2}'$$

$$\therefore\ x = 26^\circ\ 58'\ 53''$$

Now, the strike of the fissure *a b* is 118° 7½′; therefore, the strike of the line of intersection $S c C = 118° 7\frac{1}{2}' + 26° 58' 53'' = 145° 6' 23''$.

If, in the example given, it was found necessary to drive 11 yards from *c* towards *b*, in order to reach the lost lode at *l*, the sinking H of the hanging-wall of the dislocator, must, according to Zimmermann, have amounted to

$$H = \frac{11 \cdot \sin 31° 52\frac{1}{2}''}{\cos 55° \cdot \cos 31° 52\frac{1}{2}'' + \text{cotan}\, 82° 30' \cdot \sin 55°}$$

$$= 9{\cdot}76381 \text{ yards.}$$

Irregularities of Seams and Beds.—Bedded deposits are frequently found to be interrupted by *faults*, causing a cutting-off of the bed, and a displacement of it up or down. A small fault is sometimes termed a *hitch* or *trouble*. In order to represent the direction of the displacement, the fault is described as an *up-throw* or *down-throw*.

The alterations in position of stratified deposits undergone since their deposition, may be divided into three classes—(1) Faults caused by folding of the strata; (2) throws or faults caused by fissures; (3) displaced faults. Faults of the first and third class are only met with in folded strata; faults of the second class also occur in horizontal strata. All these faults give rise to dislocation of beds and seams, and rules have been formulated, like those for lodes, for ascertaining the direction in which to search for the displaced bed or seam.

Faults of the first class are, as A. Heim first showed, merely the final result of folding. In many cases, the progressive steps may be observed in the strike of the same fault. The mode of formation of such faults must therefore be considered, not as a hypothesis, but as an absolute well-established fact. Thus, at the Mansfeld Mine near Langendreer, a folded fault is very apparent in a certain cross-cut, whilst 162 feet further north it becomes a simple folding. Folded faults can only occur in beds and seams, but not in veins, for these, being filled-up fissures, are of more recent age than the country rock, and its foldings. With faults of this kind, the same seam is frequently met several times at one level. If a fault is recognised as belonging to the folded class, the direction in which to search for the displaced seam may easily be decided by means of a sectional sketch.

Throws, or normal faults, are those which have arisen entirely through the slipping down of the strata on the hanging-wall of the dislocator. The rule for ascertaining the direction in which to search for the displaced seam is as follows:—If the dislocating fissure is met on its hanging-wall, the displaced seam must be sought in the direction of the hanging-wall of the strata after the fissure is passed through. Conversely, if the fault is dipping from you, you must proceed downwards. Zimmermann's construction is applicable to dislocated seams as well as veins.

Faults of the third class were first observed by Professor Koehler in the Westphalian coal-fields, and subsequently in the lodes of the Harz. Under the term displaced faults (Verschiebungen) are to be understood those dislocations, in which a part of the previously folded or vertical strata, with the seams contained therein, was torn away, by the force that caused the folding, from another part of the strata, and slid or pushed away. In such cases, the seams and the strata appeared curved in the direction of the movement, and gradually thinned out, though no folding is to be observed, as is the case with folded faults. In addition, the plane of disruption exhibits traces of the movement in the form of slickensides and striations.

These displaced faults may thus be easily distinguished from other faults. A fault having been recognised as belonging to this category, the displaced portion of the seam may be found by crossing the plane of disruption, and seeking the shifted portion of the deposit on the side towards which that plane is inclined.[*]

Subsidence and Draw.—Interesting problems are presented by the surface subsidence caused by the removal of coal in the mine. By means of very accurate levelling, Mr. J. S. Dixon[†] made a valuable series of observations at Bent Colliery on the subject of the subsidence and draw from working the coal; the facts disclosed upsetting many old rule-of-thumb ideas on the subject. In order to arrive at correct conclusions in an inquiry of this kind, the best way is to select a line for a section on the surface, and peg it off, or have some other means of fixing levels that can be tested from time to time.

The line selected at Bent was at right angles to the advancing workings, and as nearly as possible on the level course of the coal. Pegs were put in at first every 100 feet, and afterwards every 50 feet. The Ell coal at this colliery was worked by the pillar-and-stall method until the middle of 1881, when the removal of the pillars was commenced. It was, however, some time before this operation reached the line along which the section was taken. The excavation was 5 feet 6 inches in height, and the superincumbent strata were allowed to fall and fill it up. The strata are of a firm nature, and the surface is mostly boulder clay.

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[*] On the dislocations of veins, beds, and seams, consult S. C. L. Schmidt, *Theorie der Verschiebungen älterer Gänge*, Frankfurt, 1810; C. Zimmermann, *Die Wiederausrichtung verworfener Gänge, Lager und Flötze*, Darmstadt, 1828; R. von Carnall, *Karstens Archiv.*, vol. ix., 1842, p. 3; H. Hoefer, *Oestr. Ztschr.*, 1881, p. 168, translated by R. W. Raymond, *Trans. Amer. Inst. M.E.*, 1882; R. Dannenberg, *Ueber Verwerfungen*, Saarbrucken, 1883; G. Koehler, *Störungen der Gänge Flötze, und Lager*, Leipzig, 1886.

[†] *Trans. Mining Inst. Scotland*, vol. vii., 1886, p. 224.

The original level of the surface before the pillars were removed is shown by the figures in the table on the next page. The pillars were removed for a distance of 240 feet back from the solid coal on January 21, 1882, and no subsidence of the surface had ensued. On May 27, 1882, the levels showed the maximum subsidence to have been 1·80 feet at peg 1650, 145 feet back from the face, and the draw—that is, the disturbance at the surface beyond the point of excavation—60 feet outwards from a point perpendicularly above the working face. On November 14, 1882, the face was 610 feet from the solid, and the subsidence from the original level was as shown in the table. On April 15, 1883, the face was 750 feet from the solid; on November 27, 1883, it was 1,060 feet distant; and on October 23, 1884, the removal of the pillars had been completed for some months, and the face was 1,230 feet from the solid. The levels were again taken on June 17, 1885; the workings being in the same position as they had been for about a year. On December 4, 1885, it was found that the subsidence had practically ceased, and the draw had not altered.

The conclusion arrived at is that subsidence from the removal of coal in this case attains its maximum towards the centre of the excavated space, and gradually decreases in each direction. The maximum subsidence was 4·00 feet, and the average from peg 1,000 to peg 1,600 was 3·76 feet, or 73 and 68 per cent. respectively of the height of the excavation. The wave of maximum subsidence regularly followed the working face at an average distance back of 186 feet, or 1 foot horizontal for each 3½ feet perpendicular. The permanent lengths of the draw may be taken as 100 feet (Nov. 14, 1882) on the one side, and 83 feet on the other (Oct. 23, 1884). At these points, the depth to the coal was 650 and 646 feet, representing a draw of 1 horizontal for each 6·5 feet perpendicular, and of 1 horizontal for each 7·78 feet perpendicular respectively.

The coal at Bent, it should be noted, dips at right angles to the line of section at an inclination of about 1 in 20.

SUBSIDENCE AT BENT COLLIERY.

Peg.	Original Level of Surface.	Subsidence from Original Level at					
	1881.	14th Nov., 1882.	5th April, 1883.	27th Nov., 1883.	23rd Oct., 1884.	17th June, 1885.	4th Dec.. 1885.
600	640·6	..	..	..	0·25	0·35	0·45
650	648·9	..	..	..	0·35	0·60	0·60
700	657·2	..	..	..	0·77	0·94	0·94
750	664·6	..	..	..	1·18	1·27	1·40
800	667·5	..	..	0·23	1·37	1·75	2·00
850	673·1	..	..	0·63	1·50	2·24	2·34
900	675·6	..	..	1·13	2·57	2·74	2·82
950	676·0	..	..	1·61	2·97	3·14	3·22
1000	677·1	..	..	2·10	3·27	3·49	3·60
1050	677·3	..	..	2·43	3·32	3·64	3·75
1100	678·8	..	0·50	2·80	3·52	3·80	4·00
1150	679·7	..	0·70	2·93	3·57	3·81	3·92
1200	680·6	..	1·20	..	3·52	3·52	3·52
1250	680·9	0·60	1·60	3·08	3·45	3·45	3·45
1300	679·2	0·40	2·00	3·03	3·42	3·42	3·42
1350	677·9	1·60	2·25	3·00	3·27	3·27	3·27
1400	677·5	1·60	2·45	3·83	3·17	3·17	3·17
1450	680·8	2·30	2·90	3·42	3·42	3·42	3·42
1500	680·1	..	3·05	3·05	3·05	3·05	3·05
1550	677·1	2·90	3·20	3·20	3·20	3·20	3·20
1600	675·5	3·00	3·00	3·00	3·00	3·00	3·00
1750	672·8	2·80	2·80	2·80	2·80	2·80	2·80
1850	663·4	1·70	1·70	1·70	1·70	1·70	1·70
1950	648·6	0·60	0·60	0·60	0·60	0·60	0·60
2000	649·7	0·04	0·04	0·04	0·04	0·04	0·04

The question is one of great importance to mine-surveyors in relation to the effect, on the surface, of mineral workings, and to the area of coal that should be left to prevent damage to buildings. It is consequently highly desirable that similar investigations should be made in other coal-fields.

From a careful study of the subsidence occurring in the Saxon coal-fields, R. Hausse,* of the Zaukeroda Colliery, has arrived at some interesting results. The direction of the plane of fracture occurring on the breaking of undermined strata is determined by the angle of fracture—that is, the angle made by the plane of fracture with the horizontal plane. Then if φ is the angle of fracture, and β the dip of the strata, the following equation is obtained:—

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* *Saechs. Jahrbuch*, 1886, p. 111; *Zeitschrift für das Berg. Hütten- und Salinenwesen*, 1907, pp. 324-446.

$$\tan \varphi = \frac{1 + \cos^2 \beta}{\sin \beta \cos \beta}.$$

Then, if β is equal to 0°, this equation becomes $\tan \varphi = \infty$, and $\varphi = 90°$; in other words, in horizontal strata the plane of fracture coincides with the line of gravity. When $\beta = 90°$, the equation again becomes $\tan \varphi = \infty$, and $\varphi = 90°$; that is to say, in vertical strata, the plane of fracture coincides with the line of gravity By means of the formula, the angle of fracture may be calculated in any case from the dip of the strata. In this way the following results are obtained:—

When β	=	0° then φ	=	90° 00′
		10°		85° 10′
		20°		80° 30′
		30°		76° 10′
		40°		73° 00′
		45°		71° 40′
		50°		70° 50′
		60°		71° 00′
		70°		74° 00′
		80°		80° 50′
		90°		90° 00′

To show how these theoretical results compare with results actually obtained in practice, the following example may be cited:—For supporting the Siemens glass works at Doehlen in Saxony, a safety pillar of 16 yards horizontal breadth was left, and, in addition to this, the last stall up to that pillar was packed with gob to a horizontal breadth of 16 yards. Assuming that a dense gob-packing is compressed to 0·6 of its original volume by the pressure of the superincumbent strata, the gob-pillar, for purposes of safety, represented a coal -pillar of $16{\cdot}0 \times 0{\cdot}6 = 9{\cdot}6$ yards in breadth. Consequently the coal-pillar and the gob-pillar together had the same effect in supporting the buildings as a coal-pillar of $16{\cdot}0 + 9{\cdot}6 = 25{\cdot}6$ yards in breadth. Notwithstanding the pillars, the surface was found to have sunk considerably.

The thickness of the coal seam was 4 yards. It dipped 12° towards the west, and had a perpendicular depth from the surface of 180 yards. Calculated from this depth and the width of the 25·6-yard pillar, the angle of fracture φ is found to be as follows:—

$$\cot \varphi = \frac{25\cdot6}{180\cdot0}\,;\ \varphi = 82^\circ\ 0'.$$

The dip β of the strata being 12°, the theoretical formula gives

$$\tan \varphi = \frac{1 + (\cos 12^\circ)^2}{\sin 12^\circ \cdot \cos 12^\circ}\,;\ \varphi = 84^\circ\ 20',$$

or 2° 20′ greater than the result obtained practically.

The theory of subsidence is ably discussed by Callon,* who lays down the following proposition:—If the coal has been removed over a certain area, and the space filled up in a seam worked by the methods adopted in Belgium and Northern France, the subsidence of the roof on the filling-up causes fractures along the perimeter of the area at right angles to the plane of stratification. The subsidence of the ground within the cylindrical space indicated by those fractures continues gradually without sensible diminution in amount quite up to the surface, whatever may be the depth of the mine.

The effect of subsidence due to coal workings has been exhaustively investigated by Mr. S. R. Kay,† who has deduced from many examples of modern practice the following empirical formula for the necessary pillar to be left under normal conditions. The formula is:—

$$r = \frac{\sqrt{3\,d} \times \sqrt[3]{t}}{0\cdot8},$$

in which d denotes the depth in yards, t the thickness excavated in feet, and r the radius of the support in yards. For example, on applying this formula, it will be found that if the depth of the seam is 400 yards and the thickness of the material excavated 4 feet, a pillar of 68 yards radius will, under normal conditions, give the necessary support.

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* "Lectures on mining delivered at the School of Mines, Paris," by J. Callon, translated by W. Galloway and C. Le Neve Foster, vol. ii., London, 1881, p. 304.

† *Min. Proc. Inst. C.E.*, vol. cxxxv., 1899, p. 114. The subject has also been dealt with by J. Dickinson, *Trans. Manchester Geol. Soc.*, vol. xxv., 1898, p. 583; by W. Galloway, *Trans. S. Wales Inst. Eng.*, vol. xx., 1898, p. 304; and by C. Menzel, *Saechs. Jahrbuch*, 1898, p. 147.

The Volume Excavated in Open Workings.—At the Tilly Forster iron ore mine, Putnam County, New York, an ingenious system of measurement has been adopted by Mr. E. K. Landis.* The mine is now worked as an open cut to a depth of 430 feet from the surface. The mine was divided into 10-foot squares, and lines were marked by stakes set well back from the edge of the pit. A wire rope was then stretched over a longitudinal line, and a trolley carrying a steel tape and a plumb-bob was traversed along it. A levelling instrument was set up at the north end, the plumb-line was dropped to the bottom, and the reading of the tape noted. The tape was then wound up until the plumb-bob coincided with the cross-hairs of the level, and the tape was again read. The results of these measurements were plotted on cross-section paper, and the volume excavated in the interval between the monthly measurements was calculated, the areas on the section being measured by a planimeter.

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* *Journ. Franklin Inst.*, vol. cl., 1900, p. 223.

CHAPTER XXI.

MINE PLANS.

Plan and Section.—For the representation of mine workings a plan and a vertical section are required. The plan is a projection of the mine workings on a horizontal plane; the section is a projection of the workings on a plane running parallel to the main longitudinal direction of the mine. With complicated and irregular mines, one section is not sufficient. In such a case, several sections have to be made in certain directions.

Metalliferous Mines.—Four drawings are necessary in order to represent a metalliferous mine—(1) the ground plan; (2) the working plan; (3) a longitudinal section; (4) a transverse section.

The ground plan gives a general representation of the whole concession. It may be on a scale of about 3 chains to the inch, and on it the boundary of the property of every land owner should be distinctly marked, and all the lodes indicated. The working plan gives a general view of the underground workings, as they would be seen from above if the ground was transparent. This plan should be drawn on a large scale, 4, 5, 8, and 10 fathoms to the inch being scales frequently used for the purpose. The longitudinal section is drawn on the supposition that a section of the ground is cut away, and that a side view of the mine is exposed. All the vertical shafts, the stopes, the dip of the ore-courses, and the surface-line with elevations of the mine buildings, will be correctly shown. The levels, diagonal shafts, and winzes will have a false appearance. The levels will appear perfectly straight however crooked their course may be, the diagonal shafts and winzes will appear perpendicular, and the cross-cuts will be represented as open doorways. The transverse section is of great value, as it shows the dip of the ore-courses. In the transverse section, the view is taken at one end of the workings, at right angles to the longitudinal section. Thus, the inclination of the shafts and winzes sunk on the lode is shown. The levels driven on the lode will be represented as open doorways; the cross-cuts are correctly shown; and all variations in the dip of the lode may be seen from the surface to the bottom of the mine.

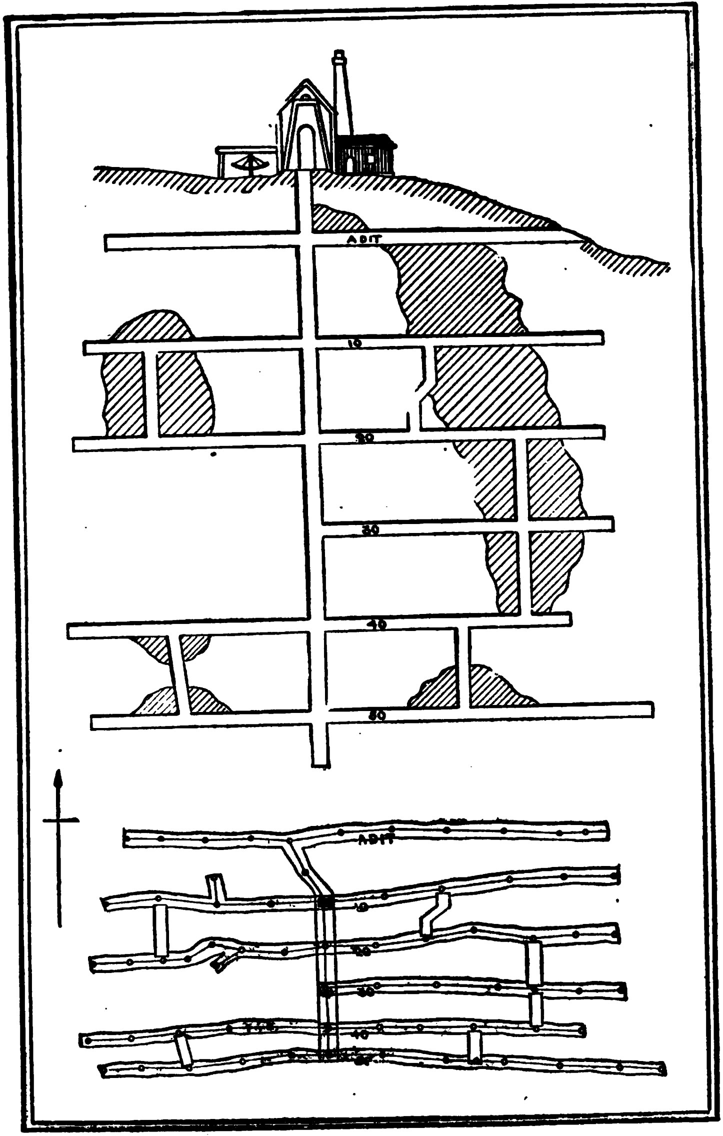

Fig. 146.—Plan and Longitudinal Section of a Metal-Mine.

When the lode is very flat, as at the Cornish mines of Wheal Jane and Wheal Kitty, the section is made along the lode. In this way a true idea is given of the ground worked; but an erroneous one with regard to depth. This method of projecting the section is necessary to enable the ground stoped away to be shown, as when the lode is so very flat, the back of one level in a vertical section would touch the floor of the next. As a rule, lodes are so nearly vertical that a perpendicular plane may be taken for the section.

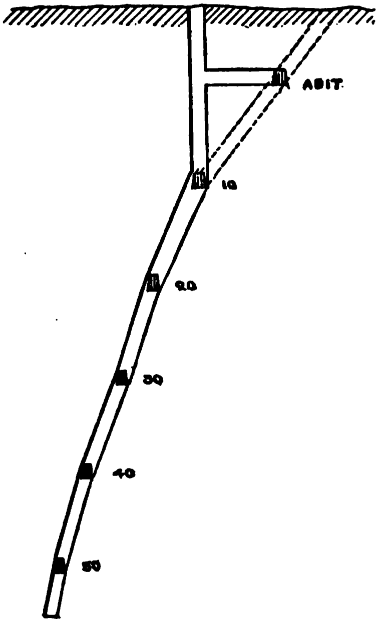

Fig. 147.—Transverse Section.

The workings of a metalliferous mine are represented in Figs. 146, 147, on a scale of about 20 fathoms to the inch. The mine has an adit-level and below that, 10-, 20-, 30-, 40-, and 50-fathom levels. The adit is north of the shaft. The engine shaft contains the pumps which lift the water from the sump or lowest point of the shaft to the adit-level, which comes out to the surface on the adjacent hill side. This shaft was sunk vertically to intersect the lode at the 10-fathom level, a cross-cut being driven to the adit. Then, instead of continuing vertically, necessitating the driving of cross-cuts to the lode, the shaft follows the latter. The shaded portions shown in the longitudinal section represent the projection of the ore masses, removed by stoping. Between the 10- and 20-fathom levels a mistake arose, the winze and rise did not meet owing to an error of the dialler.

It will be found advisable to colour all the levels on one lode the same tint. Formerly it was the general practice to colour each level a different colour, the adit-level being blue, and the levels below it red, green, yellow, violet, and brown in succession.

No scale is prescribed by law for the plans of the British metalliferous mines. The variety of scales used presents great difficulties with regard to the comparison of the plans of different neighbouring mines. In many districts, the plans are prepared in a slovenly and unsatisfactory manner. This is notably the case in the Derbyshire lead mines. There, according to Mr. A. H. Stokes, H.M. Inspector of Mines for that district, the majority of the mines have no plans whatever. Even at the larger mines which have plans, they are very roughly drawn and rarely indicate the extent to which the ore has been worked. The variable width of the levels is not shown, the latter being represented by a coloured line. The position of the best and most profitable parts of the mine—that is, the width to which the ore has been extracted, is shown as an ordinary narrow heading. In fact, the plans are not true representations of the mine, but merely represent the length of underground tramways, Sections of the mine are seldom made.

Colliery Plans.—By the Coal Mines Act, 1911, the following provisions are made with regard to plans :—

(1) The owner, agent, or manager of every mine shall keep in the office at the mine :—

(i) An accurate plan of the workings of the mine up to a date not more than three months previously, showing —

(*a*) The boundaries of the mine, where possible, and the position of the workings with regard to the surface and variations of level on the roadways from the Ordnance basis, being variations of 10 feet or any multiple of 10 feet ; and
(*b*) The general direction and rate of dip of the strata ; and
(*c*) The position, direction, and extent of every known fault of every seam with its vertical throw, and of every known wash-out and intrusive dyke ; and
(*d*) The depth of every shaft ; and

(ii) A section of the strata sunk through, or if that is not reasonably practicable, a section of every seam.

(2) The owner, agent, or manager of every mine shall also keep in the office at the mine a separate plan showing the system of ventilation in the mine, and in particular the general direction of the currents, the points where the quantity of air is measured, and the principal devices for the regulation and distribution of

the air, and on every such plan the intake airways shall be coloured blue and the return airways red.

(3) Every such plan must be on a scale of not less than 40 inches to the mile, and must be prepared by or under the supervision of a surveyor possessing the prescribed qualifications, and shall be of a durable character: Provided that in the case of a mine opened before the passing of this Act it shall be sufficient if the scale of the plan is not less than the Ordnance scale of 25 inches to the mile.

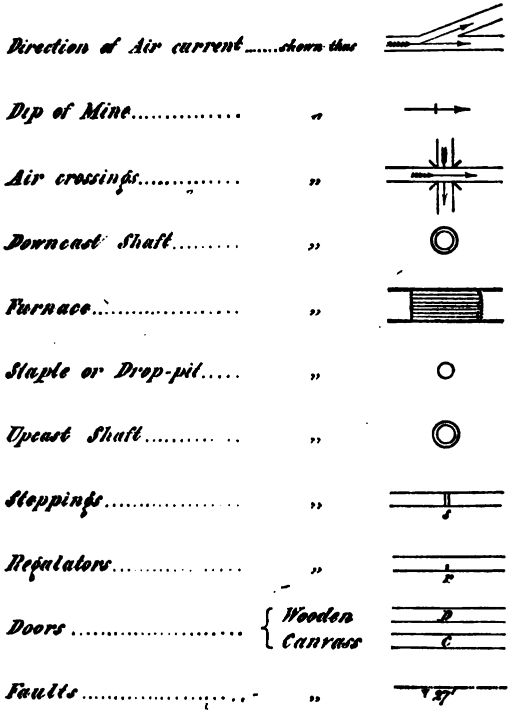
Direction of Air current ...... shown thus
Dip of Mine .... „
Air crossings .... „
Downcast Shaft .... „
Furnace .... „
Staple or Drop-pit ..... „
Upcast Shaft .... „
Stoppings .... „
s
Regulators .... „
r
Doors .... Wooden Canvass
D
C
Faults .... „
27

Fig. 148.

Representing collieries on a plan is a much more simple operation than representing metalliferous mines. The workings are projected on a horizontal plane. The coal withdrawn is indicated by colouring or preferably by hatching. The signs shown in Fig. 148 are often employed on colliery plans

A separate set of plans should be provided for each seam worked.

Admirable illustrations of the manner in which colliery plans should be executed are afforded by the plans which accompany the annual reports of H.M. Inspectors of Mines.

Surface Plans.—The surface plan of a colliery or metalliferous mine requires great distinctness of detail. If the scale of about 25 inches to the mile is adopted, the conventional signs used on the maps of the Ordnance Survey should be employed. If the scale is larger, care must be taken to give the conventional signs such dimensions as will accord with the scale of the plan. Buildings are coloured crimson lake for houses, and dark grey (a light wash of indian ink) for outbuildings. The mine buildings may be distinguished from other buildings shown on the plan by having a darker tint of red. In representing objects on the plan, their natural colours are sometimes adhered to; in other cases a conventional colour is used. Thus, for grass land, a flat tint of green (Hooker's No. 1) is employed; it is made of gamboge and indigo. Cultivated land is represented by a flat tint of burnt sienna. Adjoining fields are slightly varied in tint, furrows sometimes being indicated by coloured strips. Lakes and rivers are coloured light blue (cobalt), with a darker tint on each side. Marshes are represented by the blue of water, with horizontal spots of grass green. Roads are coloured with a light wash of burnt sienna, or yellow ochre. Hedges are represented by green dots for bushes, brick walls by a red line, and wooden fences by lines of a neutral tint. In large scale plans, the Cornish hedge, some 6 feet in width, is shown by two lines the true distance apart, with a wash of neutral tint along each side. In all cases the shadow is put in. The boundaries of the mine concession are indicated by strips of colour.

When the underground workings are drawn on the surface-plan, in the latter there should be no more colouring than necessary. It will be found sufficient to colour the roads, buildings, and water.

The colouring of extensive areas on plans used for making measurements or for plotting should be avoided, as the colouring has a very decided tendency to cause local inequalities in contraction and expansion of the paper, and may give rise to very serious errors on large plans.

American Colliery Plans.—In Pennsylvania the law requires all anthracite colliery owners to prepare maps of all workings on a scale of 100 feet to an inch for the use of the mine-inspector.

This scale is rather too large for convenient use, and consequently most of the working maps used for reference are constructed on a scale of 200 or 300 feet to the inch. These maps generally show all the important surface features, buildings, streams, roads, and railways, as well as the underground workings. The latter are commonly drawn in blue, red, or green ink. When several beds are worked, the workings are shown by different colours—a device especially necessary when the workings on one seam are above or below those opened on another bed. In addition to the general map showing all the workings, separate maps showing the workings on each seam are usually made. The survey-lines are plotted with a vernier-protractor, or a protractor of very large size, and the results checked by latitude and departure calculations. Tracings or blue-prints of the workings are supplied from time to time to the viewer. When not in use the plans are stored in large fire-proof vaults. The survey-notes are copied into office record books for future reference. With the exception of the work done by the U.S. Coast Survey, no other surveys in America can compare in accuracy with those of the anthracite mines.

The sharp foldings of the carboniferous strata of the anthracite region of Pennsylvania, have made the study of the structural geology of that region one encompassed with great difficulties. The necessity of having some definite information regarding the structure of the coal beds, before successful mining operations can be prosecuted, induced Mr. C. A. Ashburner* to introduce in 1880 a new method of representing on surface maps the underground structure of the coal beds, from which could be ascertained the situation of the outcrops of the beds, the position of the synclinal and anticlinal axes, their depths in special coal beds below the surface of the ground, and the dip of the bed from the crest of the anticlinal to the bottom of the synclinal. This was accomplished by contour lines drawn along the floor of the coal beds. The contours were obtained from elevations determined in the areas where the coal beds were mined, and from exploring the shafts, bore-holes, and surface exposures in the areas where no extensive mining had been done. In areas where no underground exploration had been made, the positions of the contours along the floors of the coal beds were deduced from surface exposures and an extension of the structure from explored areas.

Importance of Correct Sections.—The importance of keeping an accurate section of a mine is shown by a serious accident that occurred at Pantgwyn mine. On February 17, 1885, while three men were at work sinking a new shaft, water broke in suddenly and unexpectedly, and drowned them. The exact nature of the casualty will be best understood by means of Fig. 149, representing a cross-section of the mine. A B C is the old pumping and winding shaft, sunk perpendicularly for the first 20 fathoms, and then following the dip of the vein. In 1884, owing to the stoppage of some neighbouring mines, the pumping engine at Pantgwyn was unable to cope with the water, which gradually filled the workings. The owners then resolved to sink a new perpendicular shaft D E, and provide it with more powerful pumping machinery. It was intended that the new shaft should strike the Pantgwyn lode in virgin ground below any of the existing workings, which were to be drained gradually by percolation of the water through the porous vein-stone. In February, 1885, the new shaft had reached a perpendicular depth of 62 fathoms from the surface. The old shaft was then supposed to be in the position indicated by the dotted lines, and the distance between the two shafts at E was reckoned to be 40 feet. On examining the shaft as soon as it had been cleared out, the Government Inspector of Mines, Sir C. Le Neve Foster, found that the thickness of the barrier was only 9 feet; the section of the mine being incorrect. It naturally appeared to him very strange that such an error should have been made in a small survey of recent date, with two shafts less than 50 yards apart at the surface, until he ascertained that the inclination of the shaft had never been measured below the 40-fathom level. The drivages at the 55-fathom level and the 70-fathom level had been deliberately laid down on the plan just as if the shaft had been correctly dialled. The primary cause of the accident was, without doubt, the want of a correct survey. In reporting on this accident, Sir C. Le Neve Foster points out specially that it was not a case of approaching old workings, whose exact position was unknown, or imperfectly known, owing to the abandonment having taken place before there was any statutory obligation as regards the keeping of plans; but here was a new shaft, started by the same company and the same agent, within

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* *Trans. Amer. Inst. M.E.*, vol. ix., 1881, p. 50.

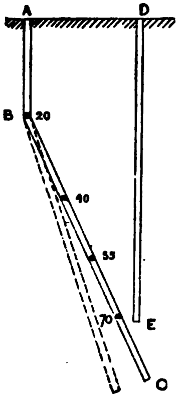

Fig. 149.

50 yards of their own workings, which had been discontinued only a few months before.

Uniformity of Scale and Conventional Signs.—In Belgium and in France the law demands that all mine plans shall be laid down on a scale of 1 : 1,000. The surface plan is prepared on the same scale as that of the underground workings. In Prussia, the scale imposed varies in the different mining districts from 1 : 500 for metalliferous mines up to 1 : 1,600 for collieries. In Austria, the scale for mine plans is usually 1 : 720. For comparison, it may be added that the scale for colliery plans in Great Britain must not be less than 1 : 2,500. Previous to 1888 the smallest scale allowed was 1 : 1,584. In America, the scale imposed in Pennsylvania for the anthracite mines is 1 : 1,200. The usual scale prescribed in the various States for the preliminary plan of a metalliferous mine-claim is 1 : 2,400.

It is desirable to have not only a uniform scale, but also uniformity in the conventional signs used in the plans. With this aim, typical mine plans have been published in Belgium by Mr. J. van Scherpenzeel-Thim; in Germany by Professor Schmidt, of the Freiberg School of Mines; in Hungary by Mr. Péch, the director of the Schemnitz mines, and in Sweden by Mr. G. Nordenström. In Prussia the law demands uniformity in the drawing of mine plans, and special rules are issued by the Government for the purpose. Unfortunately, there is a great want of uniformity in British mine plans in the various mining districts. If plans were always drawn after the same model it is evident that the working would be more uniform, and that each new mine-manager would be enabled to decipher more readily his predecessor's work. The owners, and other persons interested in mineral property, would thus be able to gain a clear understanding of the plans, and successive generations would profit by the stores of information thus recorded. Uniformity of system in the plans, too, greatly facilitates the construction of general maps of mining districts.

Preservation of Plans.—So long ago as 1797 the importance of a systematic mapping of mines was urged at Newcastle by Mr. Thomas, and since that date the value of such a system has frequently been dwelt upon for the purpose of diminishing the probability of the recurrence of fatal accidents in collieries, and of prolonging the duration of the coal resources of the United Kingdom. It is always a matter of regret that faithful records of all underground work in important mining districts have not been carefully preserved. The importance of the preservation of such records was strongly urged by Mr. T. Sopwith in 1844. In the United Kingdom plans of all abandoned mines are now carefully preserved. The Coal Mines Act, 1911, requires that where any mine or seam is abandoned, the owner of the mine or seam at the time of its abandonment shall, within three months after the abandonment, send to the Secretary of State—

(i) An accurate plan of the mine or seam, showing—

- (*a*) The boundaries of the workings of the mine or seam, including not only the working faces but also all headings in advance thereof, up to the time of the abandonment;
- (*b*) The pillars of coal or other mineral remaining unworked;
- (*c*) The position, direction, and extent of every known fault or dislocation of the seam with its vertical throw;
- (*d*) The position of the workings with regard to the surface boundary;
- (*e*) The general direction and rate of dip of the strata; and
- (*f*) A statement of the depth of the shaft from the surface to the seam abandoned; and

(ii) A section of the strata sunk through, or, if that is not reasonably practicable, a statement of the depth of the shaft with a section of the seam.

Every such plan must be on a scale of not less than that of the Ordnance Survey of twenty-five inches to the mile, in the case of a mine opened before the passing of this Act, and on a scale of not less than forty inches to the mile in the case of a mine opened after the passing of this Act, and its accuracy must be certified, so far as is reasonably practicable, by a surveyor possessing the prescribed qualifications, and it shall be of a durable character.

At the Home Office the mine plans are preserved, rolled in cylindrical lacquered tin cases, closed with a lid, on which a number is painted. The cases are placed side by side on shelves, so that their numbers can be at once seen. At Freiberg a similar plan is adopted. This method is very cumbrous. A better method is to keep the plans without being rolled or folded in portfolios. At Przibram, in Bohemia, the plans are kept in a nest of drawers, each drawer forming the frame of a plan placed between two sheets of glass.

Sopwith entirely dispensed with the large and unwieldy rolls of paper on which the workings of collieries and metalliferous mines are usually projected, by drawing the plans on imperial drawing paper. Each sheet was divided into squares of 20 inches, forming an area of 400 square inches. An inch margin was left at the top and bottom of the sheet, and 3 inches at one side for binding a series of plans into a volume. At the other side a margin of 1 inch was left, with a column 5 inches wide for the insertion of written descriptions, scales, titles, references, and other explanations of value as permanent records, with which the plan itself ought to be encumbered as little as possible. In this way, plans are kept perfectly flat, and their accuracy is not affected by the tension of the paper caused by frequent rolling. Rolled plans, on the other hand, soon become so cracked and defaced, as greatly to impair the clearness and accuracy of the plotting, whilst their bulk is a hindrance to frequent inspection and to the plotting of new workings.

Practical Hints for Constructing Mine Plans.—The paper on which the plan is drawn should be the best hard drawing-paper. If plans are required on canvas, the paper should be mounted and carefully dried before the plan is begun, in order that the contraction in drying may not alter the lines. To mount the paper, a piece of linen or calico, rather larger than the plan is required to be, is placed on a tilted table with a flat surface. A strip, 1½ inches wide, at the edges is glued, and pressed on the table, the linen being at the same time pulled tight. With large sheets, two persons pulling at opposite sides are required. The paper is then placed with its right side on the linen. Its back is then pasted until the paper becomes quite limp, with the moisture soaked in. The paper is lifted up carefully, and placed with the pasted side on the linen, and pressed from the centre to the edges. The rubbing-down may be done with the hand or with a cloth; in either case a sheet of clean paper is interposed. Paper thus mounted may be drawn upon nearly as well as when stretched on a board. To give an edge for the T-square, if required, a straight edge may be temporarily nailed on.

If several sheets of drawing-paper have to be joined end to end, the edges to be joined should be reduced to half their thickness. This may be done with a knife or with sand-paper.

In mounting and joining drawings, a great deal depends on the paste employed. It must be sufficiently liquid and contain no lumps. To prepare it, a small portion of good starch is made into a perfectly smooth paste with as small a quantity as possible of cold water, and to this solution boiling water is poured with continual stirring of the starch-paste thus formed.

Plans may be varnished by applying several coats of isinglass size, allowing each to dry before applying the next, and finishing with a coat of Canada balsam diluted with oil of turpentine.

The lead-pencil used for plan-drawing should not be very hard nor very soft. The degree of hardness marked HH is the most suitable. The quality may be tested by holding the point in a candle-flame. Good pencils suffer no change in this experiment, whilst bad leads burn away to ash with a sulphurous odour. It is best to use two pencils; one with a flat or chisel point for line drawing, and one with a point in the shape of a very acute cone for sketching.

Short lines should be drawn with the rolling parallel ruler. The plotting scale should never be used for this purpose. Straight edges, used for drawing long lines, may be tested by drawing a line along the edge of the ruler, then laying the ruler on the other side of the line, with the ends exactly upon it, and drawing a line in the same manner. If the straight-edge is true, these lines will exactly coincide; if not, the error is rendered apparent by being doubled.

For inking-in plans, indian ink is always employed, as it does nor corrode the steel points of the instrument and preserves its colour unchanged. The best ink, as imported from China, has a finely granular texture and a conchoidal iridescent fracture. When rubbed with water on a slab, it is not gritty, and smells like musk. Inferior ink smells like camphor, and the worst ink smells like soot and glue. The latter is useless for plan-drawing, as it runs when other colours are passed over it. Indian ink is prepared for use by rubbing it with water on a perfectly smooth slab or saucer. It should only be rubbed backwards and forwards, as, for some unexplained reason, rubbing it round and round hardens it. The preparation must be perfectly black; but after it has become black, further mixing renders it viscous.

For removing pencil lines and for cleaning the paper, native india-rubber, vulcanised india-rubber, or stale bread may be employed.

The drawing instruments should be of the best workmanship, as accurate results cannot be obtained with imperfect instruments. Very few instruments are required, a pair of compasses with a steel drawing-pen and a pencil-leg to fit, and a drawing-pen being all that is required for plan-drawing. Bow-compasses, though very useful, are not indispensable. A pair of turn-in compasses constitutes a set of instruments sufficient for most mining purposes.

The best compasses are those which are sector-jointed. The greatest care should be taken to clean steel drawing-pens every time they are put away, and common ink should never be used in them. It will be found desirable to have two of these instruments, one for fine lines and another for thick lines. When the proper opening for fine lines has been found, it is thus unnecessary to change it, as the pen can always be cleaned by passing a piece of paper between the nibs.

The most useful colours for mine plans are—for surface boundaries and underground workings, crimson lake, indigo, cobalt, Prussian blue, burnt sienna, gamboge. Purple green, and other tints may be obtained by mixing. Opaque colours, such as vermilion, red lead, and ultramarine, should be avoided. The end of the cake of colour is moistened, and rubbed with a drop of water. This is afterwards diluted to the proper tint. The art of laying-on a flat tint consists in allowing the coloured water to flow uniformly over the paper. This is done by applying, with a large camel's-hair brush, kept always moderately full, a tint across the upper part of the portion of the plan to be coloured, and by continuing it downwards from right to left and left to right alternately, never letting the edge dry. The drawing-board should be inclined towards the draughtsman, and the paper is moistened with water before the colour is applied if the portion to be coloured is irregular. A little prepared ox-gall used with the colours obviates the difficulty which often arises from the smoothness or greasiness of the paper. It is, however, almost impossible to use it too sparingly. In drawing the outlines, care should be taken that there is always a piece of clean paper between the hand and the drawing, in order to prevent any greasiness of the paper.

Neat and distinct lettering is very essential in all plans. It frequently happens that the appearance of a perfectly accurate plan is absolutely spoiled by a badly printed title. The formation of letters requires long practice. Lines drawn in pencil to be afterwards erased, will be found useful as guides. No style of lettering is more effective than the Egyptian or block letters, in which every line is of the same width. By the aid of copper stencil plates a great saving of time is effected. The lettering should be in lines parallel to the bottom of the plan; except the names of lodes, rivers, and roads, of which the general course should be followed.

The plan may be enclosed in a rectangle by a border, which usually consists of two parallel lines, one heavy and the other finer. The simplest border is the best, and time should not be wasted over ornamental corners to embellish the plan.

The plan is usually drawn so that the top of the paper represents the north. Whether this is the case or not, a meridian-line should always be drawn. The north point is sometimes drawn in the form of an ornamental star. When it represents the magnetic meridian, the abbreviation *mag. mer.*, with the date and declination, should be written by the side of it. A scale should invariably be drawn on the plan, with a description of it written above.

Copying Plans.—Plans may be copied by means of geometrical methods employed to determine the points of the plan by intersections or by co-ordinates. The operations are, however, very tedious. In preference to geometrical methods, there are several mechanical methods which should be employed.

Copying on Tracing-Paper. — A sheet of tracing-paper or tracing-cloth is fastened with drawing-pins over the plan to be copied. The lines are then copied in indian ink, a set square being used for ruling the straight lines. The tracing is mounted on white paper, and colour is then applied. If tracing-cloth is used, it will be found advisable to use the dull side of the cloth as the drawing-surface. In copying plans on tracing-cloth, considerable difficulty is experienced, owing to the greasy nature of the surface, in getting the ink to run freely. This can easily be obviated by sprinkling the surface of the cloth with finely-powdered chalk or pipeclay. The powder should be well rubbed over the cloth and, finally, no loose powder left.

Copying by Transfer. — The transfer-paper used for this purpose is made of thin tissue paper, one side of which is rubbed with black-lead powder, smoothly spread with a cotton rag. The transfer-paper is placed with its prepared face downwards on the clean paper. Over it is placed a tracing on paper of the plan to be copied, and all the lines are gone over with an agate point, or other blunt-pointed instrument. In this way, a copy of the original plan is obtained in black lines, which may be afterwards inked in.

Pricking-Through.—In this method, the clean paper is fixed on a drawing board, and the plan over it. All the angular points in the latter are then pricked through with a very fine needle. The points obtained on the clean paper in this way are joined up, and the plan inked in

Copying by Photography.—Photographic processes present the advantages of rapidity and fidelity of reproduction. The apparatus necessary includes thin bluish tracing-paper, printing frames of thick plate-glass hinged at the back, with a piece of thick soft felt for equalising the pressure exerted by the springs or clamps, a developing bath, non-actinic lighting arrangements (yellow window blinds by day, and a ruby lantern by night), and cases for storing paper. Instead of springs or clamps on the printing frame, use may be made of Street's pneumatic frame, with an air cushion, inflated by blowing, pressing uniformly over the whole surface of the frame.

The process most commonly used is the cyanotype sensitising process, invented by Sir John Herschel. White lines are produced on a blue ground with a solution of 140 grains of ferric ammonic citrate, 120 grains of potassic ferri-cyanide, and 2 ozs. of distilled water. The solution should be kept in a stoneware vessel. This process depends upon the action of light reducing the ferric salts to the ferrous state under certain conditions, one of which is the presence of organic matter, such as the size contained in the paper. The ferrous salt then combines with the potassic salt to form insoluble Prussian blue.

In these processes a sheet of paper, a little larger than the tracing to be copied, is fixed on a board, and with a sponge a thin uniform coating of the liquid is applied as rapidly as possible, and allowed to stand in non-actinic light until perfectly dry. The tracing is placed against the glass of the printing frame, and at the back of the tracing the prepared sheet is placed. The frame is then exposed to light until the prepared sheet becomes of a dark olive-green colour. The sheet is then removed from the frame, and thoroughly washed in pure water for a few minutes until it assumes a characteristic shade of blue.

On the Ordnance Survey, Willis' platinotype process is employed. It gives white lines on a black ground, and is based on the reducing action of a ferrous salt, when exposed to actinic light, on platinum chloride. The sensitising solution is composed of 60 grains of potassic-platinous chloride, 60 grains of ferric oxalate, and 1 oz. of water. The exposure lasts until the paper acquires a dull orange tint. It is then developed in non-actinic light by floating it for 4 seconds in a solution of 130 grains of potassic oxalate and 1 oz. of water at a temperature of 150° to 200° F. When properly developed, the print is washed for

10 minutes in 1 part of hydrochloric acid with 60 parts of water, and finally washed in relays of fresh water, for 15 minutes.*

Reducing and Enlarging Plans.—A plan may be reduced or enlarged, by taking from the original a fraction of the dimensions as required. For this purpose proportional compasses, or scales, may be employed. A very rapid method of reducing or enlarging plans consists in covering the original with a network of squares, and the copy with a network of squares having their sides smaller than those of the original squares in the proportion in which the plan is to be reduced. The details may then be sketched in by the eye. This method may also be used for copying plans on the same scale.

Plans may be reduced by mechanism by means of instruments called the *pantograph* and *eidograph*. The pantograph is made in various forms. It consists essentially of four brass rulers, E D, D B, F G, and G C, Fig. 150, jointed together at F, D, C, and G, so as to form a parallelogram. The two sides D C and D F are extended to double their length. The side F G and the branch F E are marked with successive divisions, F P being to D P always in the ratio of F A to D T. Small sockets for holding a pencil or tracing point are placed at P and T. The point A is made the centre of motion and rests on a fulcrum weight. From the property of similar triangles, the three points, A, P, and T must range in the same straight line, shown by the dotted line P A T, which is divided at A in the ratio required. Thus, while the point T is moved over the lines of the plan, the point P will trace out a similar figure reduced in the proportion of T A to A P or of D F to F P, the proportion required.

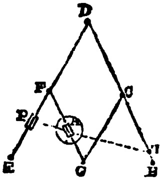

Fig. 150.

The eidograph is more complicated in construction. Although not so frequently used as the pantograph, it is superior to that instrument, within the range of its working powers, which may be considered to be limited to reducing between the full size of the original and one-third of the size. Its great merit is that within its range it reduces accurately in all proportions; for instance, it will reduce in the proportion of 9 to 25 as readily as 1 to 2.*

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* Eight other processes for the photographic copying of engineering drawings are described by B. H. Thwaite, *Min. Proc. Inst. C.E.*, vol. lxxxvi., 1886, p. 312. At the Tamarack mine the plans are photographed every month. A continuous record is thus obtained with plans of convenient size.

Plans may be enlarged by any of the methods given for reducing them. It is, however, always better to make a fresh plan from the original notes.

Isometric Plans of Mines.—The kind of drawing adopted for representing the interior of mines, and the vertical surfaces of sections of strata, is that which supposes the eye of the observer to be placed in a direction exactly perpendicular to every part of the plane represented. In this way, two drawings are necessary—the ground plan and section. By means of isometric projection, these drawings may be embodied in one, in which all the lines of the projection may be measured by a uniform scale.

A solid body, the chief planes of which are at right angles, the cube for instance, is to be so placed that the three planes which meet together at one corner are equally inclined to the horizontal plane, that is the plane of projection. The three lines which meet at that corner will then be projected so as to form three equal angles of 120° each, and will be the plans of the three edges of the cube. The plans of the opposite edges will be parallel to these, and hence it follows that in isometric projection all angles which are in reality right angles are projected into angles of 120° or 60°.

In making an isometric plan of a mine, three lines must first be drawn, making angles of 120° with one another, for the plans of three edges of the solid, in which it is imagined that the mine is enclosed. An isometric scale must then be constructed, so that the isometric lengths of the required edges may be found. When found, these are measured on the lines drawn from their plans, and the drawing is completed by parallels.

It is known that the relation of a line to its isometric projection is as $\sqrt{3}$ to $\sqrt{2}$. To construct an isometric scale, two lines must therefore be drawn in this ratio. For this purpose, a line 1 unit in length is taken, and at one end of it a perpendicular is erected of the same length, and the ends joined. The hypothenuse of this right-angled triangle will represent $\sqrt{2}$ (Euclid I., 47). If from one end of this line representing $\sqrt{2}$ a perpendicular 1 unit in length is erected, and this triangle completed, the hypothenuse will represent $\sqrt{3}$. Two lines are thus obtained representing $\sqrt{2}$ and $\sqrt{3}$ in the required relation for the scale, and if the real lengths of the edges be measured along $\sqrt{3}$ and perpendiculars dropped from their ends to $\sqrt{2}$, the parts thereby intercepted will be the isometric plans of the required edges.

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* A full description of this instrument is given in W. F. Stanley's *Mathematical Drawing Instruments*, London, 1900, p. 139.

In making an isometric plan of a mine, it is desirable that a north and south line may form one side of the supposed isometric square that regulates the drawing, the cross-lines being of course east and west. The survey must be plotted by means of the calculated latitudes and departures, the distances being set off along the edges of isometric squares. This method is of great value for elucidating questions of stratigraphy and for solving problems relating to the intersection of lodes. The necessity of referring every object to an isometric plane, however, renders its application to all the minute details of extensive subterranean workings not only tedious and difficult, but also less explanatory than the ground plans and sections in common use.*

Relief-Plans and Mine Models.—Instead of use being made of isometric projection for representing the three dimensions of mine-workings on a plan, it is frequently necessary to construct a relief-plan or model of wood, plaster, concrete, glass, or wire.

When a plastic material, such as clay, wax, or putty, is used, metal or wooden pins are driven into the base or level datum plane of wood, the top of the pins giving the elevations required. A contour plan, of the same horizontal scale as that selected for the model, is first spread upon the base-board. The pins are then driven firmly through the contour lines into the board, the tops left standing at a sufficient distance from the latter, to represent the height of the various contour lines, according to the vertical scale adopted for the model. After the pins are all properly set, the plastic material is worked into position over and thoroughly covering the pins. The process was employed in the construction of a model, exhibited at the Paris Exhibition of 1878, representing the No. 8 seam of the Loire collieries, which is intersected by an inextricable network of faults of different ages. The model was constructed for the instruction of mine-deputies, who find it difficult to follow the dislocation caused by these faults, more especially the dislocations of faults by other faults of different age.

This method was also employed by Mr. C. A. Ashburner in the construction of an interesting model of the Panther Creek Coal Basin, Pennsylvania, showing the shape of the floor of the bed. After the construction of contours in explored areas, the most important aid to the determination of the geological structure of the coal beds in areas where surface exposures cannot be obtained, is the construction of a model with the vertical and horizontal scales the same. The first area so mapped in Pennsylvania was the Panther Creek Basin, one of the most complicated basins of the anthracite district of that State. Many of the difficulties were not understood until a model was made of the floor of the Mammoth coal bed, the thickest and most valuable bed mined in Pennsylvania. A map was first made on a scale of 800 feet to the inch, upon which contour lines were shown along the floor of the Mammoth bed, 50 feet vertically apart, in the areas worked and explored. In the areas included between the two classes, theoretical contour lines were drawn on the map, in accordance with the dip of the exposed strata. Thus, the final model, made in wood and wax, not only formed a graphic representation of the structure of the strata in a highly plicated district, but also proved of great value in the definition of its geological structure, and in the deduction of many conclusions affecting the amount of coal contained in this coal basin, and the proper methods to pursue in its ultimate mining.

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* Some excellent isometric plans of mines are given in T. Sopwith's *Treatise on Isometrical Drawing*, London, 2nd ed., 1838.

The method adopted by Mr. T. Sopwith in the construction of his well-known models was as follows:—A square representing a portion of the mining district, one mile in extent, is divided into 64 squares by parallel lines a furlong apart. Sections along the eighteen lines are drawn and cut out in pasteboard or in thin plates of copper. These are then joined crossways by half-lapping—that is, by cutting each section half-way down—where it crosses another section cut in the same way on the other edge. The model of hollow squares thus formed is placed on a plane surface, and the spaces are filled in with wood or plaster, carved or moulded, so as to represent the surface. The model of part of the lead-mining district of Alston Moor, in Cumberland, exhibited in the Museum of Practical Geology, in London, was constructed by this method by Mr. Sopwith. The model shows the thickness and dip of the limestone, sandstone, and clay beds. The mineral veins are seen on the sides of the model dipping in nearly a vertical direction through the various strata.

Probably the best method of constructing relief plans is that adopted by Mr. M. Moulton in 1876 for a map of the State of New Hampshire. The map was 16 feet long, the highest elevation being 6½ inches above the datum. From a copy of the map of the State on tracing-cloth, the datum sea-level line and the contour line next above it, were transferred through the cloth on to a layer of wood, ½ inch in thickness, of the same size as the map. The outside line was drawn in blue and the inside in red. The outer contour was then cut round with a fret-saw, thus breaking off the wood outside the sea-level line. The pedestal on which the map was to be fixed then received the first layer of wood. The next layer was then prepared for sawing, as in the first case, the outside line being the first 500-foot contour and the inside or red line the next above. This having been cut out with the saw, it was nailed and glued to the first layer, its position being fixed by the red line on the latter. Throughout the work the red lines served as guides by which each successive layer was properly placed. After three layers were fixed, the steps were carved off to produce smooth slopes at angles corresponding to those of the map. Each successive group of three layers was treated in the same way.

A complete view of the nature of a mineral vein and of the excavations upon it, is given by a model constructed by Mr. T. B. Jordan, in the Museum of Practical Geology. The workings of each successive stage of 10 fathoms, are laid out on a scale of 10 fathoms to the inch on a horizontal frame of light wires crossing at intervals representing 10 fathoms, and the portions of the vein which have been worked between the levels are shown in their true position. Hence, on looking down from above, the eye may trace all the bendings of the lode, and can appreciate the comparative richness and poverty of different parts. The model represents the Holmbush mine, in Cornwall, a mine of a complicated character from the occurrence of workings on cross-courses as well as on lodes. The excavations made are represented in colours, while the solid ground is left blank.

The workings on each vein are distinguished by a special colour. Although affording a perfect view of the general arrangement of a mine, this method is too cumbrous and expensive to be generally employed.

An excellent method of constructing mine models is illustrated by three models of Austrian salt mines exhibited in the Museum of Practical Geology. These models are constructed to a uniform scale of 400 feet to 1 inch. The irregularities of the surface of the ground are represented, and central, transverse, and longitudinal sections are drawn on the sides of each model. On removing the tops of the models, representing the surface, the workings on the different levels are seen plotted on plates of glass, fixed at the proper height, one above the other. The colours of the workings shown on the glass plates, correspond with those of the named levels on the longitudinal sections. An outer line, drawn in discontinuous bars, shows the extent of the deposit of salt at each level.* A fine model of this kind, representing the Copper Queen Mine, Arizona, was exhibited in 1893 at the Chicago Exposition.

At the Stockholm School of Mines, the students are trained in the representation of mine workings on sheets of glass. The advantage of the method is the power of simultaneously representing the underground workings and the surface.

During the last thirty years mine models have been largely used in Sweden. They are of two types. When a model is to be made of a mine with a small number of levels (6 to 8), the contours of the working areas and the geological conditions in each level are painted in oil-colours on glass plates. Then these glass plates are placed one above the other, and at a distance from each other exactly in proportion to the distance between the different levels represented, so that each glass will have a perfectly true position in relation to the others.

If, on the other hand, a model is to be made of a mine with a larger number of levels, these glass models cannot be used, on account of the difficulty of seeing through a number of superimposed sheets of glass. Another method must be resorted to. The different levels are cut out of stiff white pasteboard on which the ores, etc., are marked with the proper colours. Then these sections are fastened on squares of wire stretched on wooden frames, which are placed one over the other so that each will have its exact position in relation to the others.

In addition to the practical value and advantage of mine models to the geologist and miner, such models will frequently be found of great advantage in suits at law, in settling mining claims and damages in dispute, when ordinary plans are unavailing.†

Mine Plans in the Upper Harz.—During recent years the plans of the Upper Harz metal mines have been thoroughly revised by Professor O. Brathuhn. All the measurements have been referred to one system of co-ordinates and to a common datum line. As origin for the system of co-ordinates the centre of the stone pillar in the Clausthal Magnetic Observatory was selected, and, as abscissæ axis, a line whose azimuth makes an angle of 30° with the meridian of the origin. The consequence is that the abscissæ axis is at right angles to the strike of most of the veins worked. The datum line was taken at 600 metres above sea-level, and, consequently, all the workings are below it, and only negative heights have to be dealt with. In connection with the triangulation of the State Survey, a network of small triangles was laid over the whole region. All the triangulation points are carefully marked with stones, and form an excellent basis for all future surveys. The number of stations thus marked amounts to 200. For the underground surveys the theodolite was used exclusively, and the method of working with fixed points was adopted, as local conditions render this most suitable. At each level a large number of angle-points remain marked in the hard rock, and these may be used for connecting subsequent surveys. Orientation was effected by means of the magnetic needle. No other method could be used, inasmuch as the connection between the surface and underground surveys had usually to be carried out by means of one inclined shaft. The magnetic theodolite was used, in which the magnetic needle is suspended by a cocoon fibre, and provided with a collimation arrangement. For the observation of the variation, two declinometers, a recording and a Gauss reading declinometer, were provided. The determinations of heights were effected in the levels, which are usually horizontal, by geometrical levelling, in the inclined shafts by means of steel measuring rods, the parts of which can be screwed together as required, and in the perpendicular shafts by means of a suspended plumb-line. There was rarely need to have recourse to trigonometric levelling. The special mine plans are drawn to a scale 1 to 500 on sheets measuring 50 cm. by 70 cm. (19·7 in. by 27·5 in.). A separate plan is prepared for each level, and the workings are shown by means of dotted lines on the plan of the next level. The number of sheets amounts to 270. Besides these, general plans to the scale of 1 to 2,000 are contemplated. The elaborate system of water supply for the Upper Harz mines is shown on a separate plan and section drawn to the scale of 1 to 12,500. A relief plan showing the district affected by the water supply has also been prepared on a scale of 1 to 12,500.

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* The method of working these mines is fully described by Mr. H. Bauerman in *A Descriptive Catalogue of the Geological, Mining, and Metallurgical Models in the Museum of Practical Geology*, London, 1865.

† On the construction of models, see A. E. Lehman, *Trans. Amer. Inst. M.E.*, vol. xiv., 1886, p. 439; O. B. Harden, *ib.*, vol. x., p. 264; L. M. Haupt, *The Topographer*, New York, 1883.

Colliery Plans in Westphalia.—In the course of an exhaustive account of the Saarbrücken and Westphalian collieries, Mr. V. Waltl describes in detail the methods of mine-surveying in vogue in those districts. For the whole of the Saarbrücken coalfield co-ordinates have been determined, the base line of which, the ordinate axis, forms an angle of 62° 46′ 44″ with the astronomical meridian. This base line is parallel to the main strike of the seams. All surface- and underground-surveys are referred to these co-ordinates. At surface, triangulation points are determined, and these are connected by traversing. Underground-surveys of slight importance are made with the compass. This is graduated, according to the usual German method, in twice twelve hours. The fixed points in the mines are indicated by brass marks in the roof or floor. More important length measurements are made with a 30-metre steel band, which is used in conjunction with a dynamometer in order to show the tension of the band. For accurate measurements the Bonn Mining Department prescribes measurements with rods along a stretched cord. Compass-surveys are plotted with the protractor, the compass plotting-instrument having fallen into disuse. For important operations a theodolite, reading to thirty seconds, is used, the horizontal circle being divided into 360°. Theodolite-surveys are invariably worked out trigonometrically, and plotted by means of co-ordinates. Heights are determined with a levelling instrument, and referred to sea-level. For the use of the mine-surveying office plans are prepared on a scale of 1 to 1,000. These are known as fundamental plans. They are covered with squares representing distances of 50 metres or 100 metres. From these fundamental plans all other plans are reduced by the pantograph. These include the working plans on a scale of 1 to 4,000 for the colliery managers, and on a scale of 1 to 2,000 for the overmen, and ventilation and drainage plans on a scale of 1 to 2,000 to at most 1 to 4,000. These are frequently mounted on cardboard. Coalfields maps are plotted on a scale of 1 to 10,000.

Mine Plans in Sweden.—According to the regulations of the Swedish Mining Act, all plans and sections of ore mines must be drawn on a scale of 1 to 800, and must be made in conformity with a Normal Map, drawn up by the Mining Department. All shafts and other excavations must be shown on the plans. Further, both the parts of the excavation where ore of different kinds occur and that occupied by the country, gangues, dykes, etc., must be distinctly marked with certain specified colours. It is decreed that no more than one horizontal section may be drawn on each sheet, and this rule has been followed in Sweden ever since mine plans first came into use in 1628. The mine plans made in this way give a very clear idea, not only of the configuration of the excavation, but also of the mode of occurrence of the ores contained in the mine.

According to the Mining Act, it is also decreed that all mine plans must be drawn in duplicate. One of these copies is to be kept at the mine, and the other is to be forwarded to the Office of Mine Maps belonging to the Board of Trade at Stockholm, where there is thus a complete collection of all the mine plans in the country. It is also prescribed that in all mines which are being worked every new piece of work must be surveyed, at the latest, in the year after it is begun, and it is the mine-owner's duty to forward these supplementary surveys to the Office of Mining-Maps, so that the collection of plans at this office is revised from year to year.

CHAPTER XXII.

APPLICATIONS OF THE MAGNETIC-NEEDLE IN MINING.

Exploring for Iron Ore.—In exploring for magnetic iron ores, the magnetic-needle affords valuable aid, and has been employed for that purpose in Sweden and in the United States.*

The theory of its use is based upon the fact that certain minerals deposited in the earth become magnetic by induction under the influence of the earth's magnetism, and that, consequently, the two poles are fixed in the direction of the magnetic meridian, or, more exactly, in the direction of the magnetic inclination at the opposite ends of the deposit. It is well known that there are substances, such as steel and magnetite, exhibiting polar magnetism—that is to say, they retain the magnetism once acquired even if the inducing force ceases to act. Other substances, such as soft iron and magnetic pyrites, exhibit simple magnetism; in other words, they are magnetic only so long as the induction remains.

The intensity of the magnetism exhibited by deposits of magnetite varies greatly, and is frequently so slight that only delicate instruments and practised observers can detect it; in other cases the needle is affected at considerable distances. It must, of course, be remembered that a given magnetic force affects the needle to exactly the same degree through 100 feet of rock as through the same distance of air.

If the magnetic north pole of the earth is regarded as negative, and the south pole as positive (in the northern hemisphere), the upper end of a vertical mass of ore will be negative, and the lower end positive. Consequently, if a magnetic-needle is brought near the upper or negative pole of the deposit, the north-seeking or positive end of the needle will be attracted. When the point of observation is very near the ore pole the needle will dip downwards. The lower or positive pole of the ore mass, being usually situated at a considerable depth, will not affect the observation. Other deposits, coursing in a more or less easterly and westerly direction, are less affected by induction; the poles being situated in the long sides of the deposit. Frequently the deposits are faulted and broken. In this case the separate portions behave like fragments of a broken bar magnet, the adjacent ends exhibiting opposite polarity. In exploring for ore, then, if, on advancing from south to north, the free needle is first attracted and then repelled, a fault in the deposit is indicated.

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* See paper on the "Use of the Magnetic-Needle in exploring for Iron Ore," by B. H. Brough, *Journ. Iron and Steel Inst.*, 1887, p. 289.

To explore for ore the ordinary miner's dial may be employed. If a straight line is followed with the instrument, the needle will remain directed towards the same point of the dial; or, in other words, will remain in the magnetic meridian as long as it is kept sufficiently far away from iron and magnetic ore masses. But if these are approached, the needle will gradually be deflected. The only case in which there will be no deflection is when the attracting deposit is approached along the meridian passing over its upper pole. It follows that in magnetic surveys the meridian line must first be found, and fixed in the field or on the plan. For this purpose at least two straight lines are set out in the magnetic east and west direction, from 30 to 50 yards apart. These lines will at some point cross the meridian line. If the dial is set up at one end of a line of this kind, at a considerable distance from the magnetic mass, there will, of course, be no attraction. On approaching the meridian the needle will be gradually attracted, and at a certain distance the maximum attraction will be reached. On approaching nearer it will become smaller, until, at the ore meridian itself, it will be inappreciable. The angles of deflection observed at the various stations are noted on pegs driven into the ground, and also in the field-book, or on the plan. Following the same straight line to the other side of the zero point—or, what is the same thing, to the other side of the ore meridian—the same attractions are exhibited, but in reversed order; the needle turning back to the meridian. If similar observations are made along the second east and west line it is easy to fix the ore meridian by joining the two points where there is no deflection. These points are midway between the two points of maximum deflection. This passes over the upper pole of the deposit, and if the pole is approached along the meridian line, the dip of the north-seeking end of the needle will, as a rule, be greater the nearer it comes to the pole. This method is, however, not adapted for fixing the position of the pole exactly. This may be done by determining the isogonic lines—that is to say, by joining the points where the needle has the same deflection.

In order to obtain one or more parallel isogonic lines on both sides of the ore meridian, it is necessary to set out a number of lines parallel to the ore meridian, and from 10 to 30 yards apart. At the points where these lines intersect the east and west lines, the angles of deflection must be observed, and isogonic lines constructed by joining the points of equal deflection. The needle being drawn so much out of its horizontal position that its free play is hindered, it must be weighted and balanced by a piece of wax. If, now, from some point of intersection in the network of squares made on the field of observations, a line is drawn in the direction of the deflection of the magnetic-needle, it will cut the isogonic curve at a second point, and, eventually, the ore meridian. The two points, where the isogonic line is cut, are joined; the joining line is bisected, and at the point of bisection a perpendicular is erected; then, perpendicularly under the point where this cuts the meridian, is the upper ore pole, and at this point it will eventually be found best to sink the shaft, so as to be certain of cutting the ore mass. The ore meridian, it must be noted, need not always be a straight line.

In cases where a better instrument was not available, excellent results have, in this way, been obtained with the ordinary pocket-compass, held in the hand.

For preliminary magnetic surveys, no instrument is better than the Swedish compass. In this instrument, the needle, besides revolving in a horizontal plane in the usual manner, can also turn in a vertical plane to an angle of about 60° with the horizon. The needle is horizontally suspended in a brass case on a long vertical brass pin by means of a long glass cap. The brass terminates above in a short steel point, on which the glass cap rotates. At the bottom of this is a brass stirrup, provided with fine holes, through which pass the horizontal pins supporting the needle. To enable the needle to dip, there is a long slot cut along the middle of it. The compass-box can be suspended by means of three strings passing through three small rings fastened 120° apart on the outside of the box. It can thus be easily carried in the hand. Graduation is not usual, and, indeed, unnecessary. Only the cardinal points are marked, as in using it deviations from the horizontal position alone have to be noticed. This compass was invented in the eighteenth century by the celebrated Swedish miner, Daniel Tilas, and is still in general use. The dip of the needle is estimated merely by the eye, and is not actually measured.

The miner's or dip-compass was invented in the United States in 1866, and was adopted by the Geological Survey of New Jersey in the systematic explorations for magnetic iron ore in that State. In this instrument the magnetic-needle is suspended so as to move readily in a vertical direction; the angle of inclination being measured upon the divided rim of a small compass-box. The needle cannot move horizontally. The construction of the instrument is shown in the accompanying figure. When in use, the ring is held in the hand, and the compass-box, by its own weight, takes a veitical position. It must, of course, be held in the plane of the magnetic meridian, which can be determined by holding the instrument horizontally. In this way it serves as an ordinary pocket-compass. Messrs. W. & L. E. Gurley, of Troy, New York, make several different forms of this instrument. One form has a 3-inch needle; its case has the two sides of glass. Another form has a brass back and cover, and a 2½-inch needle. Fig. 151 represents an improved compass by the same makers. It is a modification of the Swedish compass, and has a needle 3 or 4 inches long, resting upon a vertical pivot, so as to move freely in a horizontal plane, and thus place itself in the magnetic meridian; while being attached to the needle-cap by two delicate pivots, one on each side, it is free to dip. It is usually provided with brass covers on both sides.

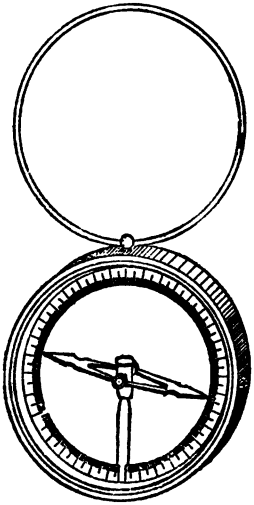

Fig. 151.

With the dip-compass, whether Swedish or American, perfectly trustworthy results can only be obtained when the observer is acquainted by long experience with the peculiarities of his instrument. Compass explorations being in many cases the sole source of income, it can easily be understood that a skilful operator will be inclined to keep his mode of procedure secret. Consequently the uninitiated are apt to believe that the operator must be specially gifted; and frequently the supernatural properties formerly ascribed to the divining-rod are transferred to the compass. This excess of faith in some is accompanied by scepticism in others. For this, unfortunately, there are good grounds; the compass being so admirably adapted for dishonest purposes. Thus, Mr. T. B. Brooks mentions an American prospector whose compass-needle in the vicinity of an ore mass always showed a dip of 90° when facing west, and the true dip due to local attraction when facing east. The former position, it is said, was very successfully used in selling iron ore grounds, and the latter in buying them. Similarly in Sweden a powerful magnet inserted in a walking-stick has been successfully employed to give a large dip to the needle when it was thought desirable to mislead the purchaser.

As a rule, surveyors assume that the most ore must occur where the dip-compass shows the greatest inclination, or is perpendicular. This assumption, however, is erroneous. The place where the needle is attracted most by a vertical ore bed is not directly above, but to the north of, the south pole of the deposit. For, if the magnetism of the earth is powerful enough, there must be somewhere north of the ore pole a point at which the horizontal components of the magnetism of the earth and of the ore bed are equally powerful, but acting in opposite directions. At this point the horizontal forces neutralise each other, and then the vertical forces of the magnetism of the earth and of the ore bed tend to bring the needle into a vertical position.

The evidences afforded by the needle often lead to error. A small pocket of ore near the surface may act as strongly as a larger ore mass situated far below the surface.

It is thus seen that in exploring for iron ore with the magnetic-needle, a purely scientific method is necessary. The compass should be employed for preliminary work, in order to save time and labour; but before a shaft is sunk, recourse should be had to a more accurate method. Improved methods, available for the purpose, have been devised by Brooks, Thalén, and Tiberg.

1. **Brooks' Method.**—Mr. T. B. Brooks,* of the Geological Survey of Michigan, in exploring for iron ore, determined with a pocket-compass variations east and west; the bearings of a standard line being taken as in ordinary surveys. The inclinations or dips were observed on the dip-compass held in the hand in the plane of the meridian. Sometimes observations were made with the compass held at right angles to this position, that

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* *Geological Survey of Michigan*, vol. i., 1873, chap. viii. See also "Magnetic Observations in Geological Mapping," by H. L. Smyth, *Trans. Amer. Inst. M.E.*, vol. xxvi., 1896, p. 640

is, facing north and south. The instrument was always held in the hand and levelled by its own weight. The intensity of the magnetic force for the three positions of the compass was measured by the number of oscillations made by the needle in a unit of time, usually taken at a quarter of a minute. No attempt was made to eliminate the earth's attraction by neutralising it with a magnet while the observation was being made, nor by computation; and the great amount of friction in the compass renders the number of oscillations only an approximation to the number that would be obtained with a delicately mounted needle. Mr. Brooks has, however, done excellent work with this method in the Marquette region and in New York and New Jersey. He also describes another method of working, which he calls magnetic triangulation. The mode of procedure is as follows:—Remote from any magnetic rocks, neutralise, by means of a bar magnet, the earth's influence on the needle of a solar compass. The needle will then stand indifferently in all directions. If the compensated instrument is set up near the magnetic pole to be determined, the needle will point as nearly towards the local pole as its mode of mounting will permit. The operation being repeated at two other points near the magnetic pole, the three lines must intersect in one point, which will be directly over the pole of which the position is sought. By using a dip-compass in a similar manner, data to determine the depth would be obtained. The fact that several local poles often influence the needle at each station renders this method difficult in practice; a place must be sought where but one strong pole exists.

2. **Thalén's Method.**—Professor R. Thalén,[*] of the University of Upsala, employs a modification of Weber's portable magnetometer, or of Lamont's theodolite. In its simplest form, Thalén's instrument consists of a compass-box, A (Figs. 152, 153), 3½ inches in diameter, divided into degrees or half-degrees. At right angles to the diameter, passing through the zero point of the graduation, an arm, B, extends horizontally. This serves as a sight in setting out lines in the field, and receives the bar magnet C for the deviation measurements. A deflection of the needle is caused by means of this magnet, the longitudinal direction of which is parallel to the arm, and the distance of which from the needle always remains unaltered. On the other side of the compass-box there is a socket, into which a rod of soft iron can be placed perpendicularly for inclination measurements. This iron rod,

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[*] *Jernkontorets annaler*, vol. xxxiv., 1879, p. 17.

like the magnet, effects a deflection of the needle The instrument rotates about a vertical axis, and is provided with a spirit level, D, sights, E and F, and levelling screws. It is placed on a tripod. In order to simplify the apparatus still further, the compass-box may be fastened to a rectangular board, the edges of which can be used as sights; whilst the board itself receives the bar magnet, which is fixed by screws or springs in the position that is determined once for all. As support for the instrument, an ordinary surveyor's plane table may be employed.

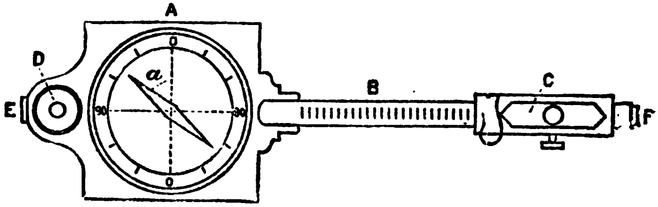

Fig. 152.

The observations with the magnetometer consist for the most part of deviation measurements, for which two different methods may be employed. In one method the instrument is placed so that the needle is directed to the zero point, the bar magnet having been removed from its place. Directly the magnet is replaced, the needle will deviate from its original position, the angle of deviation being read from the graduated circle. In the second method the instrument is turned, while the magnet is in its

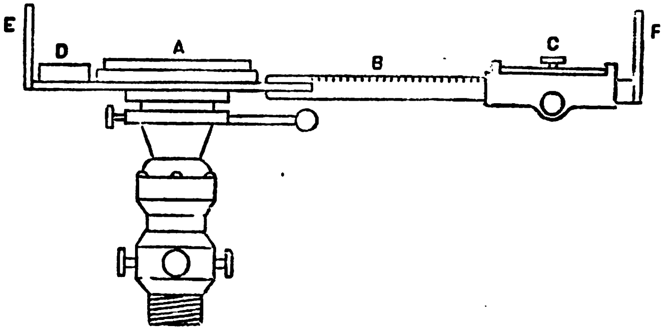

Fig. 153

place, until the needle points to zero. The bar magnet is then removed, and, when the needle has come to rest, the angle is read. In this method, under similar conditions, the angle obtained will be greater than in the former method. Of the two methods, the latter, or *sine method*, is the more delicate; but it requires more time than the former, as the instrument has to be readjusted at every observation with the magnet and iron rod. This method has the disadvantage of not being applicable in the extreme north of the ore field, where the magnetism of the ore bed is powerful. In the former, or *tangent method*, the instrument remains unmoved during both measurements. The disadvantage, however, is that the so-called constants of the instrument vary with the angle of deviation. This does not matter if the results are to be arrived at geometrically, since it is then merely necessary to join the points where the same angle is obtained, quite regardless of the magnitude of the angle and of its corresponding constant. If the position of the ore is to be determined by calculation, the sine method must be employed.

Where no ore is present, the needle is acted upon by two forces, one of which is due to the fixed magnet, and the other to the horizontal component of the earth's magnetism. These two forces acting simultaneously, the needle takes up a position in the direction of their resultant. Then if a is the angle of deviation, and H the component of the earth's magnetism, the following formulæ are obtained:—

for the tangent method: $H \tan a = K_1$,
for the sine method $H \sin a = K_2$,

in which K_1 and K_2 are constants, so long as the size and position of the magnet remain unaltered. If these constants are known, the actual value of H may be found from the magnitude of the observed angle by either of the methods. If the constants are unknown, only the relative value of H may be found. When observations are made near an iron ore field, in both formulæ H must be replaced by R, the resultant of the horizontal component of the earth's magnetism and the magnetism of the deposit. The formulæ then become

$$R \tan a = K_1, \text{ and } R \sin a = K_2.$$

When the deviations are caused by the soft iron rod instead of by the magnet, somewhat similar formulæ are obtained; but the magnetism of the iron rod being due to induction, its intensity is proportional to the variations of the vertical components of the earth's magnetism. It follows that the constant K of each formula in this case must be replaced by a magnitude that varies with the magnetism of the rod. Observations with the iron rod indicate the inclination of the earth's magnetism; whilst observations with the bar magnet serve for determining the horizontal components of the same terrestrial force. Consequently, by combining the two methods, it is possible to find out the vertical components of the magnetic force.

In order to survey an ore field, it must first be divided into squares with sides 100, 50, or 25 feet in length. Then at every angle of these squares, the deviation must be observed with the magnet and iron rod. Similar observations must be made on ground free from iron, and so far distant from the ore field that the influence of the ore is not felt. It is also advisable to determine the magnetic declination for each point of observation. This may be done by directing the sights along one of the lines that have been set out, and reading the bearing, after the fixed magnet and iron rod have been removed. Observations must also be made along the magnetic meridian north of the supposed ore pole to determine where the north-seeking end of the free needle changes its direction from north to south, or whether it invariably points towards the north.

When these determinations of declination, horizontal intensity, and inclination have been carefully made, and the angles obtained noted on paper divided into squares, lines are drawn for each of the three series of observations, exhibiting equal declination (isogonic lines), equal intensity (isodynamic lines), and equal inclination (isoclinic lines). This is done in each case by joining the points at which equal angles were obtained. The curvature of the lines is drawn as naturally as possible, care being taken to avoid sharp bends. The curves of inclination and intensity thus constructed are closed, and have an approximately circular or elliptical shape, provided that a single isolated ore mass is being dealt with. They are grouped round two points. The one at the north is where the greatest angle of deviation was found, whilst that at the south is where the smallest angle was obtained. Between these two groups of curves is an open curved line representing the neutral angle. In this neutral line the intensity is the same as if no ore was present. The straight line joining the points where the greatest and smallest angles were obtained passes over the centre of the ore mass, and indicates the direction of the magnetic meridian of the ore field. Directly beneath a point in this line, in a vertical ore bed, the greatest mass of ore occurs. The rule that most generally holds good in searching for iron ore is, that the ore mass is to be found immediately beneath the point where the magnetic meridian cuts the neutral line.

The isogonic lines consist of concentric ovals placed, as a rule, symmetrically on both sides of the meridian. From the shape and position of these curves useful indications may be obtained regarding the position of the ore pole, and the shape of the deposit.

The mode of procedure can best be understood from the accompanying ideal map (Fig. 154), drawn by Prof. G. Nordenström.*

Before the measurements are begun, the instrument is adjusted at a place where there is no magnetic force other than the earth's magnetism. The angle of deviation found here is noted a_0, and is generally so arranged that it is equal to 25° or 30°. Then begins the measurement of the ore field, which for this purpose is divided into squares with sides 10 metres in length. By the aid of the tangent method the angle of deviation, a, is afterwards obtained in each corner of every square. These a-values are noted on a map, and the points for which equal angles have been obtained are joined. This gives two systems of isodynamic curves, which are grouped in a more or less regular manner around their foci or centres. One of these is situated north of the ore and where the a-value is greatest, and is therefore noted as a-maximum; the other is situated either directly above the greatest mass of ore or somewhat to the south of it, and represents the smallest a-value, being therefore noted as a-minimum. Between these two groups of curves there is an open curved line, whose angle of deviation is the same as obtained in regions where there is no ore, and it is noted as a_0. This curved line is called a neutral line, the angle a_0 being called a neutral angle.

The line which unites the maximum point and the minimum point indicates the direction of the magnetic meridian of the ore field. The centre of the greatest mass of ore is situated in the point of intersection of the magnetic meridian and the neutral line when sin a_0 is less than 3 sin a-min.

In this case the outcrop of the ore is covered by beds of sand, gravel, or other deposits.

If, on the other hand, sin a_0 is equal to or greater than 3 sin

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[*] *Journal of the Iron and Steel Institute*, vol. liv., 1898, p. 51.

a-min., the centre of the ore is situated either under the point representing *a*-min., or somewhere on the magnetic meridian between this point and the point of intersection. In this case the ore either crops out at the surface, or its outcrop is covered

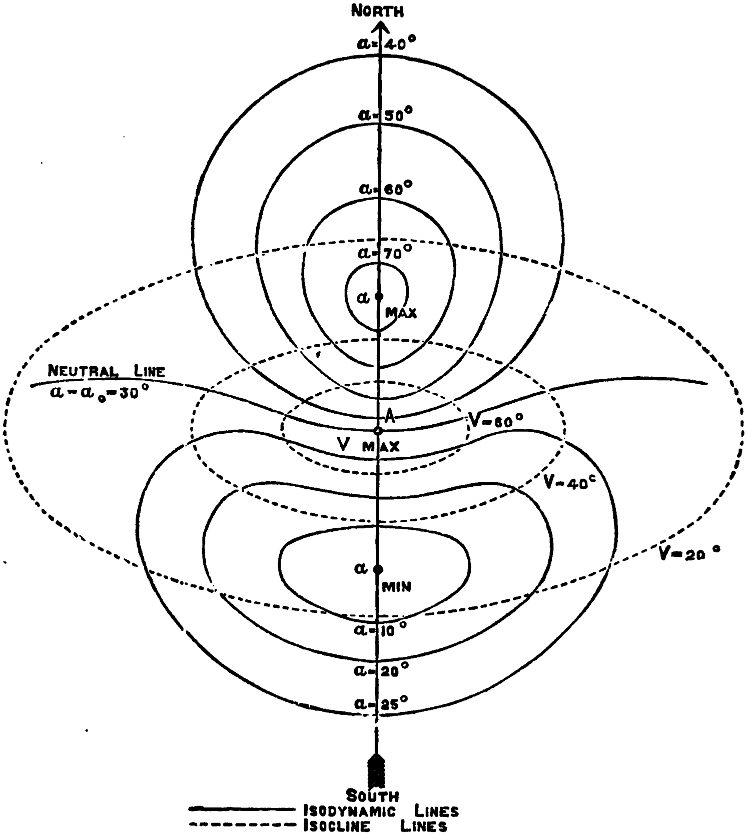

Fig. 154.

by more recent deposits, whose thickness is least when the centre of the ore is nearest to the minimum point.

Finally, it should be noticed that, in order to get correct results, the levels of the ore field which is being surveyed should be known.

3. Tiberg's Method.—For exploring for iron ore, Mr. E. Tiberg invented in 1880 a dip-compass, 3½ inches in diameter, and half an inch deep. The axis of the needle is at right angles to the plane of the box, and rests upon two agate supports. The needle can thus move freely when the compass is placed horizontally or vertically. The instrument differs from other dipping needles in that the centre of gravity of the magnetic-needle is a little below its horizontal axis when the compass is in a vertical position. The needle is compensated for the vertical force of the earth's magnetism by a piece of wax or by an aluminium counterpoise fastened to its south-seeking end.

The instrument is provided with a spirit-level for horizontal adjustment, and with a ring, by means of which it can be suspended vertically. The sighting instrument, used in conjunction with the dip-compass, is a brass plate about a foot in length, provided at one end with four square flanges to receive the dip-compass for horizontal measurements. At right angles to this square, there is a groove in the plate with a sliding receptacle for the bar magnet required for horizontal measurements. Four folding sights are attached to the plates in such a way that their lines of sight form a right angle. The instrument, consequently, can be used as a cross-head. Two special sights are added for levelling operations, and the instrument is provided with a circular spirit level.

The observations for vertical measurements are made at the surface with the plane table or by hand. The inclination instrument is fastened to the plane table, levelled, and turned until the needle points to 90°. The instrument is then raised with the ring at the top, and placed at right angles to the magnetic meridian, and the angle indicated by the needle observed. The same operation has to be done by hand if the plane table is not available. When the ore appears to be deep, or when the horizontal intensity is powerful, recourse must be had to the plane table.

The formula for calculating the vertical intensity G is—

$$G = K \tan v,$$

in which v is the angle given by the needle—that is, its deviation from the horizontal—and K a constant varying in different instruments from 0·75 to 1·4 of the earth's horizontal magnetic force. Lines of equal vertical intensity may thus be constructed. In magnetic plans it is usual to employ a blue colour for positive intensity, and a red colour for negative intensity. The accuracy attainable with this method is from 0·2 to 0·1 per cent. of the earth's magnetic force in central Sweden. With the plane table 250 to 300 observations may be made per day, and 450 to 500 by hand. For each ore field surveyed the needle must be compensated afresh, and a preliminary magnetic survey made. The field is then divided into squares, with sides 40 feet in length. The base-line is as nearly as possible in the middle of the field, and parallel to the direction of the strike of the deposit. In making the survey, observations are made every 10 feet, and in some cases every 5 feet, in the immediate vicinity of the ore, and every 20 to 40 feet or more when farther distant from the ore. The general rule is to make as many observations as may be required to indicate what the appearance of the curves will be. Heights are estimated by the eye, or by a preliminary levelling with the sighting instrument, and the more important topographical details are noted.

The maximum of intensity is generally presented by the point where the ore is nearest to the surface. It may also be situated between two adjacent deposits—in which case the intensity decreases, at first slowly, or not at all, and then comparatively rapidly. The distance to the centre of a vertical ore bed may be taken as at least 0·7 of half the breadth of the north-polar attraction. This rule is, however, not very trustworthy. The vertical distance of the plane of observation from the upper ore pole is equal to the horizontal distance of the point where the needle deviated most from the horizontal from that where ⅓ of the greatest intensity was found. It is also equal to 1⅓ of the distance of the point where the needle dipped most from that where half the maximum was found. The latter rule is the best.

Sometimes these calculations enable an opinion to be formed of the relative values of two similar ore beds. For two deposits of a similar character, situated at least 30 feet beneath the surface, it may be assumed that the deposit, for which the product of the greatest intensity and the polar distance is the greater, contains the larger quantity of ore for the same length of deposit. If the polar surfaces of the two beds are limited this product must be replaced by the square of the polar distance.

A good idea of a deposit may be formed from the appearance of the curves of intensity. Regular, long extended, elliptical curves, enclosing a long but narrow district of greatest intensity, always indicate a regular lenticular mass An asymmetrical bend in the curves indicates parallel deposits. More circular curves may indicate a segregation of ore if the intensity decreases regularly. Irregular curves indicate more or less irregular deposits.

In exploring for courses of ore in the mine, a base-line is marked out in the level, and observations made every 10 feet at least. At each station three observations have to be made:—(1) To determine the direction of the total horizontal intensity by means of the sighting instrument, the deviation of the magnetic-needle from the base-line being observed. (2) To determine the magnitude of its force by means of the bar magnet. (3) To determine the vertical intensity by means of the inclination instrument. Vertical measurements must also be made at the top and floor of the level, and for this purpose the instrument may be held in the hand. On neutral ground at the surface, the horizontal force of the earth's magnetism and the direction of the earth's magnetic meridian must be determined. The results of all the observations are represented on paper, along the base-line, as arrows showing the horizontal forces of the magnetism of the ore at the points of observation. If all or part of the arrows are directed towards the same point, there the ore may be assumed to be. The ore would be at the level at which the observations were made, if the vertical intensity is negative. When the arrows approach in front or behind, the plane of observation is above or below the magnetic centre of the ore. When the vertical intensity is positive, the ore may be above or below the plane of observation, always assuming that a more or less vertical ore mass is being dealt with.

By applying this method Mr. Tiberg has discovered important deposits of ore at the Swedish mines of Langban and Sikberg.

To illustrate the value of the magnetic-needle in exploring for iron ore, it may be mentioned that, according to the statistics given by Prof. Smock,* there were 115 mines in 1868 in the State of New Jersey, whilst in 1874 the number had increased to 200. All these ore localities were first made known by the use of the magnetic-needle. In fact, the annual production of the State had been increased 50 per cent. by the addition of new producing localities found by the compass. It should also be stated that in many cases there are no visible surface indications of ore.

4 **Combined Thalén and Tiberg Method.**—For some years past Tiberg's instrument has generally been used in combination with Thalén's magnetometer, partly to avoid the necessity of taking

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* *Trans. Amer. Inst. M.E.*, vol. iv., 1876, p. 353.

more than one instrument on surveying expeditions, and partly owing to the fact that by such a combination of the two instruments greater rapidity results, especially if the tangent method is used.

The combined instrument is illustrated in Fig. 155.

In order to make it possible to use first one and then the other of these compasses, they are provided with axle-pins fitting into the bearings in the standards, *a*, which are shown enlarged in Fig. 156. The centre-lines of the axle-pins in the Tiberg compass run through the zero-points, but in the Thalén compass through the 90° point. The instrument is furnished with a spirit-level, *b*, a transverse arm, *c*, and sights, *d*. The arm, *c*, secured on one of the standards serves to receive the bar-magnet for the deviation measurements, when measurements according to the Thalén method are to be made. The method of using the instrument in making such measurements has already been sufficiently explained.

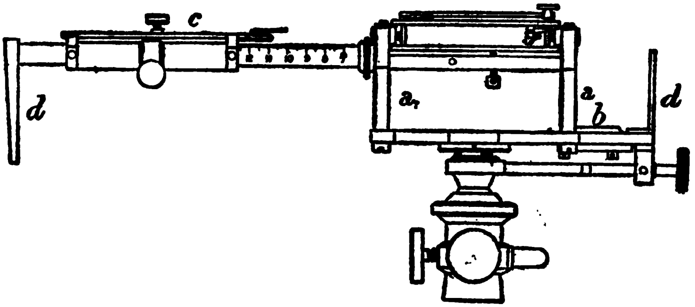

Fig. 155.

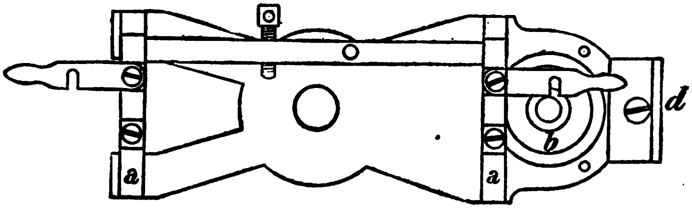

Fig. 156.

To begin with, the instrument is adjusted on perfectly neutral ground. After the ore field to be explored has been divided into squares, with sides 10 metres long, observations are made with the dip-compass at each corner of every square in the following manner:—

The compass is placed horizontally and is turned in a horizontal plane until the central line through the axle-pins of the compass is at right angles to the direction of the needle, or, in other words, until the needle is placed at 90°. Then the compass is turned on its axle-pins, so that it has a vertical position. In this position the needle is only affected by the vertical component of the ore, and this causes a greater or less inclination of the needle. If the magnetic force of the ore is P, and the angle of the inclination is V, then

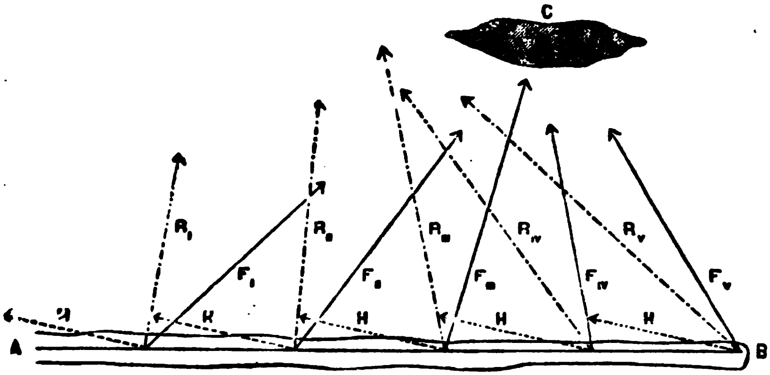

Fig. 157.

$$P = K \tan V.$$

If the value of V is noted on a plan, and the points for which the same V-values were obtained are united, there is obtained a series of curves (isoclinic curves), which are more or less regularly grouped around a centre whose V-value is greater than that of all the others (see Fig. 154). Immediately under this centre, where $V = V$ max., the greatest mass of ore always occurs.

Besides for surveys at the surface, both the magnetometer and the dip-compass are also used for surveys underground, in the mine itself, in searching for ore. For this purpose the sine method is generally used. If H (Fig. 157) is the horizontal component of the earth's magnetism, and F that of the ore, and

R the resultant of both, there is obtained for each point of observation R_1, R_2, R_3, etc., according to the formula—

$$R = H \frac{\sin a_0}{\sin a}.$$

If an arbitrary value is given to H, which is considered to be a constant, the lengths R_1, R_2, R_3, etc., as well as their direction, are ascertained. The length and direction of the component of the ore, F, are then obtained by construction.

The position of the centre of the ore sought for, C, is indicated by the direction of F_1, F_2, F_3, etc., all of which converge more or less towards this centre.

5. **Thomson-Thalén Method.**—To the instruments for magnetic-surveys of ore deposits there has recently been added the Thomson-Thalén magnetometer, which has two magnetic-needles with like poles in the same direction, the inclination produced by the vertical components of the magnetic forces acting upon them being compensated by a cylindrical magnet north pole upward. The distance of the deflecting magnet may be altered by means of a graduated brass screw, and the compensated intensity of the vertical component of a magnetic ore body is indicated on an arbitrary scale. The theory of the instrument is described by Mr. A. Haanel.*

Use of the Magnetic-Needle in Surveying Bore-holes.—It has been assumed that the diamond drill always bores a perfectly straight hole, even though passing through rocks of different hardness. Actual experience reveals an entirely different state of things, the deviations sometimes being so great as to render a bore-hole misleading. An ingenious plan of correctly ascertaining these deviations has been devised by Mr. E. F. Macgeorge,† an Australian engineer. His plan consists in lowering into the bore-hole clear glass phials filled with a hot solution of gelatine, each containing, in suspension, a magnetic-needle, free to assume the meridian direction. The phials are encased in a brass protecting tube, and let down to the depth required, being allowed to remain for several hours until the gelatine has set.

The construction of the phials or *clinostats* can be seen from Fig. 158. The clinostat is a true cylinder of glass made to fit accurately within the brass guide-tube. At the lower end it terminates in a short neck and bulb, within which a magnetic-needle is so held by a glass float as to stand upright upon its pivot in every position of the phial, and thus allow the needle to assume the meridian freely without touching the sides of the bulb. Passed through an air-tight cork and screw-capsule at the upper end is a small glass tube terminating in another bulb above and with its open lower end inserted in a cork which enters the lower neck of the phial, thus preventing the escape of the needle and float in the lower bulb. The upper bulb contains a very delicate plumb-rod of glass consisting of a fine rod terminating in a plumb of glass below and a diminutive bulbous float of hollow glass above. It is carefully adjusted to the specific gravity of the gelatine in which it is immersed, so as to ensure the rod being truly vertical whatever the position of the phial and bulb may be. When the gelatine is fluid the plummet hangs freely perpendicular, whilst the needle in the lower bulb assumes the magnetic meridian. When, however, the phial is at rest in any position, the contents solidify on cooling, and thus hold fast the indicating plummet and magnet in solid transparent material. On withdrawal from the bore-hole the phials can each be replaced at the same angle at which they cooled, and when the phial is revolved upon the part where the magnetic-needle is seen embedded in the gelatine, until the needle is again in the meridian, the phial is manifestly in the same direction, both as regard inclination and azimuth, as it was when its contents were congealed, and thus the gradient and bearings of the bore-hole can be determined. By repeating the observations at intervals of every 100 feet, the path of the bore-hole can be accurately mapped.

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* *Examination of Magnetic Ore Deposits.* Ottawa, 1904.

† *Engineering*, vol. xxxix., 1885, pp. 260, 334.

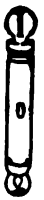

Fig. 158.

The inclination and azimuth at the time of cooling is determined exactly by the recording instrument, or *clinometer*, which is a modification of the theodolite. The phial, with its congealed contents, is placed in a sheath of brass tubing (Fig. 159), attached to a movable arm carrying the index of a vertical arc. The upper bulb of the phial is brought into the field of two cross-visioned microscopes, carried with the arm round the vertical arc, which are kept truly in the same plane at every angle of inclination by a parallel motion. Upon the object-glass of each microscope vertical lines are drawn. The phial is revolved in its sheath, and the arm is moved along the arc by the tangent screw until the embedded plummet is made perpendicular from each point of view. The phial is now at the angle of inclination at which its contents solidified, and its lower bulb will be found nearly in the axis of the revolving arm, and about an inch above the centre of a horizontal revolving circular mirror, having a system of parallel lines engraved across its face. Reflected in the mirror will be seen the image of the embedded needle, which, of course, pointed north before it was fixed by congelation in the bore-hole. If now the mirror is revolved until the number 270 of the graduated circle is opposite the marked end of the needle, and until the reflected image of the needle is parallel with the engraved lines, an index at the side of the graduated mirror frame will give the exact angle between the needle and the vertical plane of revolution of the phial, which is, in fact, the magnetic bearing of the inclined phial and of the bore-hole it occupied at the time of the application of the test.

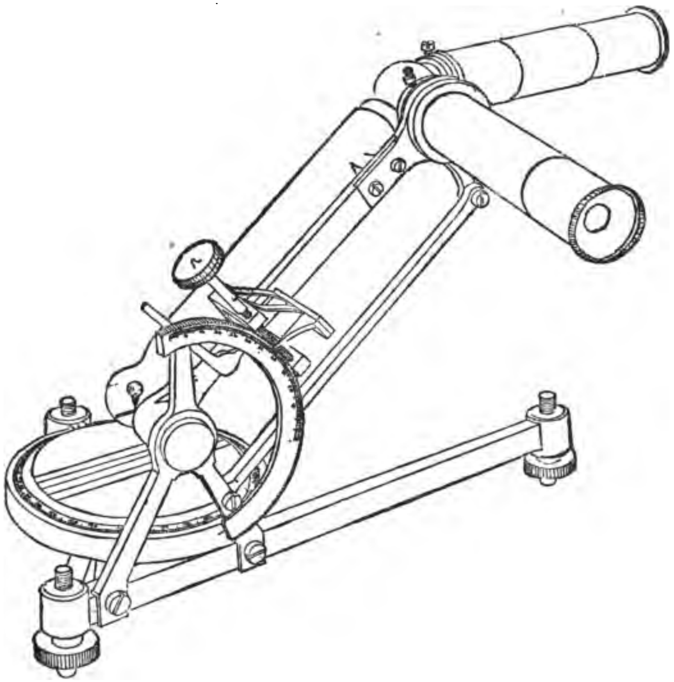

Fig. 159.

This method was first applied at the Scotchman's United Mine at Stawell, in Victoria, and was so effectual as to enable the bore-hole to be found 37 feet away from its supposed position at a depth of 370 feet, a deflection that increased to the large amount of 75 feet at a depth of 500 feet. An exploratory level failed to find the bore-hole at its theoretical position, assuming the drill to have gone straight down. The subsequent search works lasted for more than a year, and cost altogether £3,663. Had the method been available at the commencement, the level driven would have cost only £1,352, and the saving effected would have been no less than £2,311.

Similar experiences have been met with in a number of other bore-holes in the mining districts of Victoria, and the consequence is that mine-proprietors are beginning to distrust the diamond drill altogether. Yet, if accurately surveyed, the most crooked bore is quite as useful as the straightest ever imagined by drill-makers. In view of these facts, the Victorian Government has contracted with the inventor to test all approved bores which have passed through auriferous rock.

By means of the *clinograph*, as the inventor terms his apparatus, a bore may be straightened when so deflected as to endanger the safety of the drill; for, suppose a bore-hole to have deflected suddenly, the depth of the point where the most serious deflection took place can be found. Then, if an india-rubber washer is forced down to 20 feet below this point, and liquid cement run in until it reaches some feet above the point of deflection, and allowed to set, then the drill may be again lowered and started gently, until it has started fairly in its corrected path, when the usual speed of boring may be resumed.

A less satisfactory method for ascertaining the inclination and direction of bore-holes was suggested by G. Nolten.* In the instrument employed, the amount of deviation is etched upon glass by hydrofluoric acid; whilst its direction is found by means of a compass-needle, clamped by the aid of a stop-watch, after sufficient time has been allowed for settling. Notwithstanding the great imperfections of this instrument, its use in Germany has revealed some startling deviations of bore-holes. For example, in a bore-hole at Dienslaken, bored with a rotating drill, the deflection amounted to 47° at a depth of 750 feet. The bore-hole, undertaken by the German Government, at Leith, in Holstein, was but little better than the preceding; but, by a lucky accident, the deflection of 3° at 984 feet gradually changed to the opposite quarter of the compass at 1,640 and 2,624 feet, and concluded with a deflection of only 1° at 3,280 feet.

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* *Preuss. Zeitschr.*, vol. xxviii., 1879, p. 176; Translation by C. Z. Bunning and J. K. Guthrie in *Trans. N. Eng. Inst. M.E.*, vol. xxix., p. 61.

Careful observations of Rand bore-holes by Mr. J. Kitchin* show that deviation is not observed, except where the rocks passed through are bedded and have a dip. The average horizontal displacement of the twenty-two bore-holes specially examined was 440 feet, the minimum being 160 feet in a bore-hole 2,000 feet deep, and the maximum 2,370 feet in a bore-hole 4,200 feet deep.

The diamond drill has been largely used for prospecting in the West African goldfields, and valuable experience in surveying the bore-holes by the Macgeorge method has been recorded by Mr. J. N. Justice.† A preliminary survey was made for dip by the hydrofluoric acid method with very satisfactory results. In a vertical hole the tendency is to deflect along the dip of the rocks. In inclined holes set at about 45° the tendency is to become steeper. In the case of one hole inclined at 51° 30′ the distance at a depth of 773 feet measured along the assumed course of the bore-holes to the same depth along the actual course was 165 feet, and at a depth of 1,900 feet the divergence had increased to 280 feet. If the deflection is considerable, the direction has to be determined, and this is done by the aid of Macgeorge's clinostats.

A method of surveying bore-holes has been devised by Mr. G. C. M'Farlane, an American engineer, in which the inclination is determined from the deflection of a tangent galvanometer. An ingenious electric recording apparatus has also been devised by Mr. H. F. Marriott,‡ who has detected with it serious deflections at the Turf mines, Johannesburg. In one case at 4,802 feet the bore-hole had deviated 2,185 feet from the vertical line passing through the mouth of the bore-hole.

Excellent results have been obtained in Germany with Gothan's *stratameter*. This instrument comprises a compass-needle and a plumb-bob regulated by clock-work. The combined instrument is enclosed in a brass cylinder 650 mm. long and 54 mm. in diameter in such a way that the compass is at top, with clock-work on the alarum principle below, whilst the plummet, with recording plate, occupies the lower end of the cylinder. At a given time the freely swinging needle is clamped by the clock-work, and at the same time the plummet is released and its position marked.

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* *Trans. Inst. Min. Met.*, November 21, 1907.

† *Ibid.*, vol. xii., 1903, p. 301.

‡ *Ibid.*, vol. xiv., 1905, p. 255.

Employment of a Powerful Magnet in Cases of Uncertain Holing.—In 1846 Professor Borchers, of Clausthal, first proposed to employ a powerful magnet in cases of uncertain holing from one excavation to another. Since that date, he has improved the method in many ways, and has frequently employed it in practice with great success. In order to ensure a successful holing, the ends of the two levels must not be more than 20 yards apart. The apparatus employed consists of a powerful magnet, with a specially constructed protractor, a compass, and a small auxiliary magnet.

The powerful magnet consists of six magnetised steel bars 4 feet in length, enclosed in two wooden boxes, provided with water-tight lids. One of these boxes contains only one magnet; whilst the other box contains the remaining five, separated from one another in the middle and at the ends by pieces of card-board. In the centre of its upper side, the larger box is provided with a pivot, which fits into an aperture in the smaller box. On this pivot, the small box can be rotated, and the north pole of the magnet inside can thus be made to correspond with the south poles of the magnets in the large box. Consequently, a portion of the magnetic force of the latter is neutralised. The powerful magnet must be fixed in such a way that it can be pointed in various directions, without altering the position of its centre. For this purpose is employed a brass protractor, Figs. 160, 161, which can be screwed on to a thick board. At the centre of the protractor, a brass plate revolves, and between the turned-up edges of this, the principal magnet may be placed. At right angles to the longitudinal axis of the magnet, an index line is engraved. Provided the rock barrier is not more than 6 yards across, an ordinary compass, with a sensitive needle, may be employed. For greater distances, the compass-needle must be suspended by a silk fibre. Under these circumstances the steel pivot is removed from the compass, and a case screwed on to

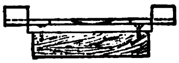

Fig. 160.

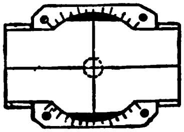

Fig. 161.

the plate, as shown in Fig. 162. The sides are covered with glass to protect the needle from air currents. The upper end of the glass tube, containing the silk fibre, is provided with a contrivance for centring the needle. The latter is somewhat longer than the diameter of the compass dial, and does not require to be centred with mathematical accuracy, provided that both ends are read, and the mean of the two readings taken. The auxiliary magnet is a small magnetised bar 12 to 18 inches in length.

The mode of procedure is the following:—At the end of one of the levels, the protractor is firmly fixed in such a way that its north and south line is in the magnetic meridian. At the end of the other level, the compass is set up, as nearly as possible at the same height as the protractor, and placed so that the needle indicates north. The needle must then be rendered astatic. To effect this, the auxiliary magnet is placed in the direction of the north and south line of the compass, on the side away from the principal magnet in the other excavation, and moved backwards and forwards until the force attracting the needle is neutralised. When these preparations are complete, the principal magnet, with the small box above it, is placed on the movable plate of the protractor, and brought approximately into the direction of holing. The powerful magnet then acts on the astatic needle of the compass, and causes it to take up a direction determined by a law enunciated by Gauss. But as the needle is not perfectly astatic for all directions, what attracting force remains must be again neutralised for the position taken up under the action of the powerful magnet. This is done by revolving on its pivot the small box above the principal magnet, until the north pole of the magnet it contains corresponds with the south poles of the other magnets. The action of the large magnet is thus diminished. Then if the compass-needle is not perfectly astatic, it will alter its position, as the attracting force of the principal magnet increases or diminishes. If a change in the position of the needle is observed during the action of the weakened magnet, attempts must be made to bring the needle back to the position it occupied when the principal magnet acted with full force, by moving the auxiliary magnet very slightly. The upper bar of the large magnet is then turned back to its

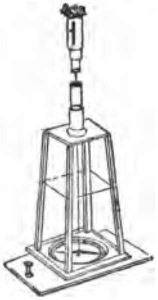

Fig. 162.

original position, and it is ascertained whether the compass needle alters its position. If this is the case, the process must be repeated until the needle gives the same bearing with the full force and with the diminished force of the large magnet.

From the bearing of the needle and the direction of the large magnet, the direction of holing may be determined by construction, in the following way:—A B C (Fig. 163) is a right-angled triangle, with the right-angle at C; A being the centre of the large magnet, the longitudinal axis of which is in the direction of the hypothenuse A B. At C is the astatic-needle, which, attracted by the large magnet, takes up a position in the line C D. The direction of this line is determined by the equation—$A D = \frac{1}{3} A B$. Strictly speaking, the magnet N S should be very small. For practical purposes, however, this law may be applied without any appreciable error.

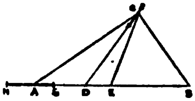

Fig. 163.

The question now arises, in what way should this law be applied. A geometrical method is inconvenient in the mine; and consequently, it is desirable to calculate the angles α (B A C) and β (A C D)—that is, the deviation of the direction of holing A C from the position of the magnet N S, and from that of the compass-needle C D. A, B, and C are situated on the circumference of a circle, the centre of which is E. In the triangle D E C, the angle C D E is equal to $\alpha + \beta$; and, since the triangle A E C is isosceles, the angle A C E is equal to the angle C A E; therefore, the angle D C E is equal to $\alpha - \beta$. The ratio of the sides D E and E C, however, is 1 : 3, and $1 : 3 = \sin(\alpha - \beta) : \sin(\alpha + \beta)$; therefore,

$$\sin(\alpha - \beta) = \tfrac{1}{3}\sin(\alpha + \beta).$$

Suppose, for example, that the bearing given by the protractor of the large magnet was 154°, and that given by the compass 125° 15′; the difference is then $28° \ 45' = \alpha + \beta$. Now, $\sin 28° \ 45' = 0{\cdot}48099$; one-third of which is 0·16033, which is the sine of the angle 9° 14′. Consequently,

$$\begin{aligned} \alpha + \beta &= 28° \ 45' \\ \alpha - \beta &= 9° \ 14' \end{aligned}$$

therefore, $\alpha = 19°$ and $\beta = 9° \ 45'$. The direction of holing A B is, therefore,

$$\begin{aligned} 125° \ 15' + 9° \ 45' &= 135° \ 0' \\ 154° \ 0' - 19° \ 0' &= 135° \ 0' \end{aligned}$$

This calculated bearing' has to be subtracted from 180°, since the north and south line of the compass always remains in the same position throughout the process; the needle being revolved. The direction in which it would be necessary to drive would, consequently, be

$$180^\circ - 135^\circ = 45^\circ.$$

Instructions for carrying out the operations required at the large magnet are given by means of previously arranged signals by the observer at the compass.

A powerful magnet was applied with success in a somewhat similar manner in 1885 by Mr. A. Haddon in seeking a bore-hole, that had diverged from the vertical, at the Holyrood Brewery, Edinburgh. After the bore-hole had gone down 200 feet, it was considered necessary to connect it by a level with a neighbouring well 18 feet 3 inches distant. The miner entrusted with the work having failed to find the bore-hole, Mr. Haddon procured four 8-inch bar-magnets, placed end to end, and secured between two laths of wood. These he lowered into the bore-hole with the south pole downwards, and, by noting the deflection of a compass-needle at different points in the mine, he found that the bore-hole was 8 feet from its expected position.

A powerful magnet was also applied with success in the mines of the Upper Harz. There, according to Mr. O. Brathuhn, on March 17, 1898, a level connecting the Kaiser Wilhelm II. shaft and the Rosenhof shaft was successfully holed. The requisite traverse had a total length of 2,600 yards, and the junction of the two roadways was effected with mathematical accuracy. The result is of special interest, inasmuch as the mine surveyor, Mr. Flachsbart, was obliged to employ a great variety of methods of surveying. He had, for example, to connect the surface- and underground-surveys by calculation, by means of plumb-lines and by means of the magnetic-needle. A special triangulation-survey of the surface had to be made, the two base lines for which afforded an opportunity of testing the steel rods subsequently used for measuring the lengths of the station lines underground. The Rosenhof shaft is an inclined one, and in the upper portions quite unsuitable for traversing. Consequently it was necessary to utilise the vertical Silbersegen shaft down to the south level. There plumb-lines and the magnetic collimator were employed, and the traverse carried down the inclined Rosenhof shaft to the seventeenth level. The average inclination of the shaft is 77°. In the shaft an eccentric theodolite was set up in three places, and horizontal and vertical angles measured. The seventeenth level to the starting-point of the new connecting roadway is over 400 yards in length and very tortuous, so that the theodolite had to be set up twenty-two times, the work being rendered difficult by the number of short lines of sight. The roadway driven from the seventeenth level contained only eight angles in a length of over 550 yards. The orientation of the seventeenth level was effected with the aid of the magnetic collimator. That of the heading driven from the Kaiser Wilhelm II. shaft was calculated with the aid of the Konigin Maria shaft over 950 yards distant. The azimuth obtained was tested by magnetic observations, and a difference of twenty-two seconds were observed. The calculated result was adopted. No difficulty was experienced in the survey of this heading, in a length of over 90 yards, the theodolite being set up only sixteen times. The length measurements were made with two 2-metre steel rods along a stretched cord, the fractions being measured with a brass metre rule divided into millimetres. The clinometer was used for determining the inclination of the cord, and each line was measured twice at least. For levelling, the starting-point selected was the level of the water in the navigable adit level, which is horizontal and 2,700 yards in length. It connects the Silbersegen and Kaiser Wilhelm shafts 760 feet above the horizon at which the connection was to be effected by this survey. Vertical depths in the inclined Rosenhof shaft were measured with Borchers' steel rods, and these appliances were also used in vertical shafts.

As the connecting roadway was intended subsequently to be used for electric haulage, an accurate junction was desirable. Consequently, when the headings were within 5 yards of each other, the direction was tested by means of a powerful magnet 165 lbs. in weight composed of six bars, in the manner proposed by Borchers.

The level of the two headings was tested in the same way. In this way an exact junction was effected. This final test is of great value to a surveyor in charge. In this case he knew five days before the holing was effected that the work had been carried out with accuracy. When the holing had been completed an accurate survey was made, and the deviations found in the two traverses were 0·142 metre in the ordinates, 0·451 metre in the abscissæ, and thirty-three seconds in the azimuth. The difference in level was found to be 1·5 millimetre

CHAPTER XXIII.

Photographic Surveying.

Photogrammetry.—The theory of the methods by which plans and sections may be obtained by means of photographs has been termed photogrammetry. The principles of photogrammetry were developed by Lambert as far back as 1759. The first application was made in the years 1791 to 1793 by Beautemps-Beaupré, who constructed topographical plans from his perspective hand-sketches made during his voyage round the world. The first camera constructed for this purpose was used in 1851 by Colonel Laussedat, who in this way surveyed a portion of Paris in 1861. Since then the method has been largely developed in Germany, Austria, and Italy, and the literature of the subject is now considerable.* The principle of the method is simple. If a photograph be taken from a point of which the position is already known, the direction of the axis of the object glass and the focal length of the lens being also known, and the line of the horizon being marked on the picture, the picture can be laid down on a sheet of paper on which it is desired to plot the survey, and will give the direction from the point of observation of all the points the position of which is required. Two photographs of the same object taken from different known points define the position of each object, and also enable altitudes to be calculated or graphically determined. In fact, the method of surveying is exactly that of the plane table, with the difference that a great portion of the work which, with the plane table, has to be done in the field is, with the photographic method, done in the office. The degree of accuracy obtainable is obviously not excessive. The method is, however, well adapted for such topographical surveys as mining engineers are sometimes called upon to execute.

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* The following are the principal works on photogrammetry:—Colonel Laussedat's exhaustive articles in the *Mémorial de l'officier du génie*, 1854, No. 16, and 1864, No. 17; "Die Photogrammetrie," by Dr. Stolze, Halle, 1887; "Die Photogrammetrie," by Dr. Koppe, Weimar, 1889; "Photography applied to Surveying," by Lieut. H. A. Reed, New York, 1888; L. P. Paganini's articles in the *Rivista di Topografia*, 1889; "Die Photographie im Dienste des Ingenieurs," by F. Steiner, Vienna, 1891; "Die Photographische Terrainaufnahme," by V. Pollack, Vienna, 1891; "Die Photographische Messkunst," by F. Schiffner, Halle, 1892; "Das Photographische Aufnehmen zu wissenschaftlichen Zwecken," by A. Meydenbauer, Berlin, 1892; "Éléments de Photogrammétrie," by V. Legros, Paris, 1892; E. Monét's article in the *Mémoires de la société des ingénieurs civils*, 1894, p. 216; "Photographic Surveying," by E. Deville, Ottawa, 1895; "Anwendung der Photographie in der Messkunst," by E. Dolezal, Halle, 1896; "Les Instruments topographiques," by A. Laussedat, Paris, 1898; "Topografia fotographica," by C. de Iriarte and L. Navarro, Madrid, 1899; and A. O. Wheeler's paper, *Trans. Inst. M.E.*, vol. xxi., 1902, p. 418.

Instruments Used.—There are many types of photo-theodolites in use. The principle is, however, the same in all. The instrument consists of an ordinary theodolite in which the telescope is replaced by a camera, whose optic axis is accurately parallel to that of a telescope placed at the side. A graduated horizontal circle and a vertical circle enable the angles to be read with accuracy, and a spirit-level fixed to the camera serves to ensure the horizontality of the instrument. The holder for the plates is provided with points of thin sheet metal which mark the horizontal and vertical lines on the picture. The point of intersection of the marking should coincide with point sighted at the cross-wires of the telescope.

A compact instrument for photographic surveying has been designed by Mr. J. Bridges Lee.* It consists essentially of a photographic camera fitted inside with a magnetic-needle, which carries a vertical transparent scale divided and numbered to 360°, and also with cross fibres which intersect at right angles. The fittings and adjustments of the instrument are of such a character that the camera can be accurately levelled and directed towards any point in a horizontal direction, and when a photograph is taken in an ordinary way the bearing of the meridian vertical plane which bisects the instrument through the photographic lens will be recorded automatically on the face of the photograph. The vertical fibre (and its image on the photograph) serves as an index to read the bearing; and the same fibre marks by its shadow a line right across the photograph, which marks the meridian vertical plane on the image. The horizontal fibre is adjusted to mark on the image the horizontal plane which bisects the photographic lens. The camera rests on a divided horizontal circle, which can be adjusted to a truly horizontal position by levelling screws. There is a tripod stand

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* *Soc. of Engineers Trans.*, 1899, p. 171.

and head, with suitable appliances for supporting and adjusting the instrument in position. The camera is provided with a rectilinear doublet lens, and iris diaphragm and rack and pinion focussing adjustment. It is made of aluminium, and it is surmounted by a telescope adjustable in altitude, and fitted with vertical and horizontal webs; and it is also surmounted by a tubular level which can be rotated.

The present form of the Bridges-Lee photo-theodolite, made by Mr. L. Casella, of London, has been adopted because experiment has proved the necessity of great nicety of mechanical adjustment to obtain the best results. One very important addition to the usefulness of the instrument is the insertion of a scale of angular distance photographically prepared by the same lens as that fitted in the instrument when complete for surveying purposes. The scale is so attached to the frame that it is photographed on every picture taken, and by its aid the angular distances of any point in the picture right or left of the median vertical plane may be read. In order to avoid possible confusion among the pictures obtained, it is found advisable to record notes indicating the number of the picture, station, altitude, and magnetic variation on the face of the picture rather than in a note book; and special provision has been made to enable this to be done easily.

The construction of the Bridges-Lee photo-theodolite is shown in Fig. 164, in which A is the aluminium box provided with a rectilinear photographic lens; C is the horizontal circle divided in half degrees with a vernier reading to minutes; E, the telescope free to rotate only in a vertical plane; in the most recent instruments the telescope is held between two supports; F, the vertical limb divided in half-degrees with vernier reading to minutes; G, revolving tubular level; H, falling-back to camera with hinged joints, and with a window of polished glass, *h′*, in the ground glass, *h*, through which the vertical index hair and compass scale can be read; I, rectangular frame of metal rigidly attached to a bottom plate that supports the compass-box; it can be racked backwards and forwards by the aid of a transverse pinion traversing the bottom of the box and terminating in two milled heads, J J. Pointers that revolve with the pinion serve to show whether the internal structures are forward or back when the falling-back of the camera has been let down, and replaced by a double dark slide containing a photographically sensitive plate. The rectangular frame, I, can pass inside the double dark slides used, when the shutters are open, and carry

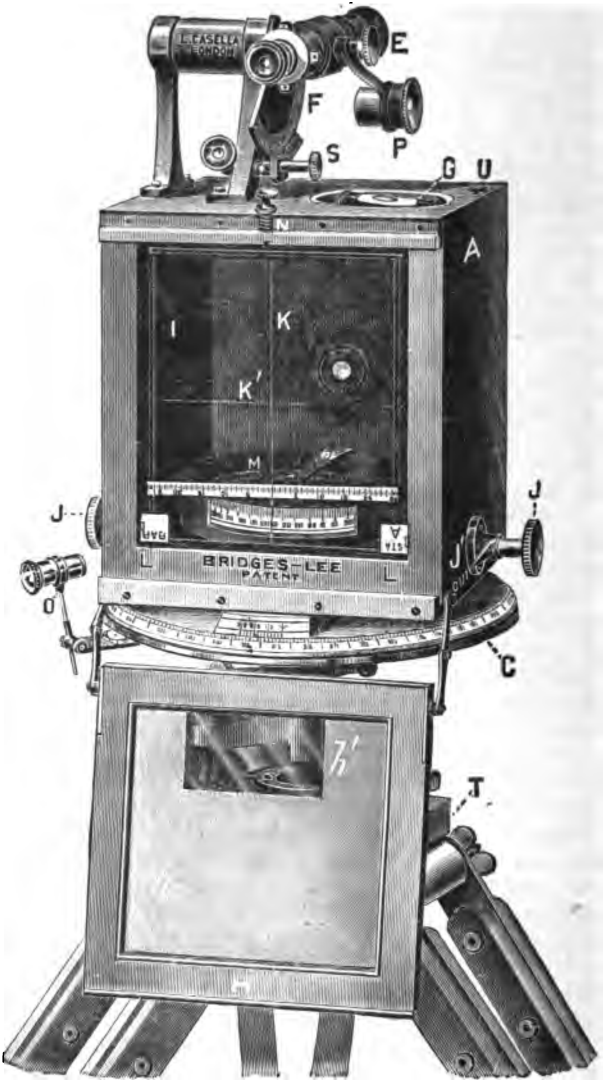

Fig. 164.—Bridges-Lee Photo-theodolite.

back the hairs, K K′, which it supports until they touch the plate. L L are small tablets of thin transparent celluloid, on which any particulars required are noted. M is a magnetic compass with vertical cylindrical transparent scale graduated in half-degrees from 0° to 360°. The scale passes close to the vertical index hair, but never touches it. N is a catch to hold the double dark slide in place. O is a microscope with universal joint movement to permit of its being used either for reading horizontal angles or compass bearings; P an adjustable microscope for reading vertical angles. S is the clamp and tangent screw for the telescope. Clamps and tangent screws (not shown in the illustration) are also provided for the horizontal circle and for the camera. The crosses marked U on the top of the box indicate the focal distance. The instrument is provided with tribrach locking plates and levelling screws, and is supported on a strong tripod. Attached to the frame, I, carrying the hairs, K K′, is a horizontal transparent scale of angular distances, photographically prepared by the aid of the identical lens and instrument used for surveying.

Application to Mining Work.—Mr. H. M. Stanley, of Arizona,* successfully employed the photographic method in a survey of the properties of the Plata-Reina de Senora Mining and Milling Company, situated in the mining district of Las Planchas, Mexico. The area surveyed comprised about 6 square miles in broken mountainous country. In order to carry out the work as quickly and as accurately as possible, it was decided to triangulate the area, and to complete the work by photographic surveying; an 8 by 10 Eastman camera being used. The first picture was taken to the north and to the right of the meridian. The others were taken round the circle, one after another, so as to slightly overlap, care being taken to note the height of the instrument and the index number for each picture.

The method of plotting employed by Mr. Stanley is illustrated in Fig. 165. The points marked "Corruscos," "Mejia," "N. Coneccion," and "N. Guadalupe" are points established by triangulation, at each of which pictures were taken. This sketch was originally constructed on a scale of ½ inch to 150 feet. The focal distance of the lens used is 20·3 half-inches.

In order to fix the point "W. Ladera," it was found on examining the pictures that this point is on VIII. Mejia and I. North Guadalupe. The first operation is to orient these pictures —*i.e.*, find and plot the position of the optical axis and of the

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* *Trans. Amer. Inst. M.E.*, vol. xx., 1891, p. 740.

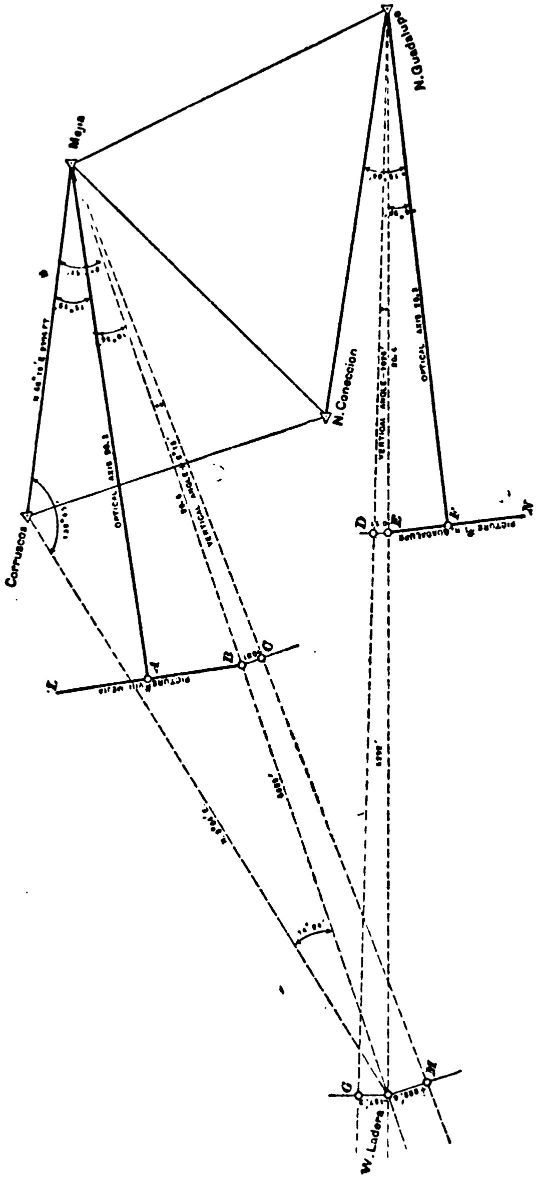
N. Guadalupe
Mejia
N. Concecion
Coppuscos
W. Ladera
A
B
C
D
E
F
G
L
M
N
OPTICAL AXIS No. 3
VERTICAL ANGLE
PICTURE
OPTICAL AXIS No. 3

Fig. 165.

picture in each case. On VIII. Mejia, the point "Corruscos" is known. Mark it (1) on the back of the negative. With the dividers measure carefully the horizontal distance from this point to the vertical axis. From a diagonal scale of equal parts constructed on a half-inch, the horizontal distance is found to be + 5·53 half-inches, or units, and as it is to the right of the vertical axis it is marked plus. This distance is the altitude of a right-angled triangle whose base is the focal distance of the lens. The hypothenuse is the distance from the optical centre of the lens to the image of the known point on the picture, in this case "Corruscos." The tangent of the angle at the base of the right-angled triangle is equal to

$$\frac{+\,5{\cdot}53}{20{\cdot}3} = +\,0{\cdot}27241.$$

The orientation angle is therefore + 15° 15′.

This result is placed in the proper column of a table ruled as follows :—

Photographic Survey of....................................

SCALE, ½ inch = 150 feet. FOCAL DISTANCE, 20·3

STATION.	View No.	Point No.	Co-ordinate Horizontal.	Co-ordinate Vertical.	Orientation Angle.	Location Angle.	Vertical Angle.	Height of Point above or below Station.	Height of Station above or below Datum.	Height of Point above or below Datum.	Distance.	Remarks.
Mejia, . . .	VIII	1	+5·53	..	+15°15	..	..	..	..	..	..	Oriented on Corruscos Flag.
N. Guadalupe,	I	1	+5·47	..	+15°04′	..	..	..	..	..	..	Oriented on N. Conceccion Flag
Mejia, . . .	VIII	2	−3·80	+0·81	..	−10° 36′	+2°15′	+222′·8	+500′·0	+722′·8	5668′	Location of W. Ladera Flag.
N. Guadalupe,	I	2	+2·35	−0·51	..	+ 6° 36′	−1°26′	- 157′·3	+880′·1	+722′·8	6292′	Location of W. Ladera Flag.

To plot the position of the optical axis, draw a line through the station Mejia, making with the hypothenuse, Mejia-Corruscos, an angle equal to − 15° 15′—*i.e.*, to the left. Make this line equal to 20·3 half-inches or units and it will be the optical axis. A line perpendicular to it at its extremity will be the position of the picture VIII. Mejia. In the same manner the picture I. N. Guadalupe may be oriented as shown on the sketch, using for the purpose point (1) of that picture, which is the flag at N. Coneccion. The calculation in this case is :—

$$\text{Tangent of the angle} = \frac{+5{\cdot}47}{20{\cdot}3} = +0{\cdot}26945.$$

Orientation angle = + 15° 04′.

The two pictures having been oriented, the positions of all points common to them both may be determined. On picture VIII. Mejia, it is seen that the point W. Ladera, point (2), is — 3·80 units to the left of the vertical axis, and + 0·81 unit above the horizontal axis. The same point (2) on the picture I. N. Guadalupe, is + 2·35 units to the right of the vertical axis, and — 0·51 unit below the horizon. These results are recorded on the calculation-sheet. Now,

$$\frac{-3{\cdot}80}{20{\cdot}3} = \text{tangent of angle} = -0{\cdot}18719.$$

Location angle = — 10° 36′.

At the point Mejia draw the line Mejia-W. Ladera, making with the optical axis an angle equal to — 10° 36′—that is, to the left of the optical axis.

From picture I. N. Guadalupe it is found that

$$\frac{+2{\cdot}35}{20{\cdot}3} = \text{tangent of angle} = +0{\cdot}11576.$$

Location-angle = + 6° 36′.

At the point N. Guadalupe draw the line N. Guadalupe-W. Ladera, making an angle with the optical axis of picture I. N. Guadalupe, equal to + 6° 36′—that is, to the right of the optical axis. The intersection of the two lines Mejia-W. Ladera and N. Guadalupe-W. Ladera is the position of the point W. Ladera which was required.

This point could have been determined graphically. On the line L A B lay off A B = — 3·80. Through B and Mejia draw the line Mejia-W. Ladera. On the line D F N lay off F E = + 2·35, and draw N. Guadalupe-E-W. Ladera. These two lines will intersect at W. Ladera. The distance Mejia-W. Ladera, and also N. Guadalupe-W. Ladera are scaled from the map and placed in the proper column of the calculation-sheet.

To find the elevation of W. Ladera, or its depression above or below Mejia and N. Guadalupe, the procedure is ;—Through the point, B, draw B C perpendicular to B-Mejia, and make it equal to $+0{\cdot}81$ unit. Through Mejia and C draw the line Mejia-C-M. At W. Ladera draw W. Ladera-M perpendicular to Mejia-W. Ladera. Then the line W. Ladera-M is the elevation of W. Ladera above Mejia, and it may be scaled and placed on the calculation-sheet.

At E draw D E perpendicular to the line N. Guadalupe-W. Ladera and equal to $-0{\cdot}51$ unit and at W. Ladera draw W. Ladera-G perpendicular to the same line. Through N. Guadalupe and D draw N. Guadalupe-D-G. Then W. Ladera-G is the depression of W. Ladera below N. Guadalupe. Scale this, and place it on the calculation-sheet.

To calculate the elevation—

In the right-angled triangle Mejia-A-B, the side Mejia-B $= \dfrac{20{\cdot}3}{\cos 10^\circ 36'} = 20{\cdot}6$ units.

In the right-angled triangle Mejia-B-C, the tangent of angle at base $= \dfrac{0{\cdot}81}{20{\cdot}6} = 0{\cdot}03932$; the angle of elevation $= 2^\circ 15'$.

In the triangle Mejia-W. Ladera-M, the side W. Ladera-M $= 5668 \times \tan 2^\circ 15' = 222{\cdot}8$ feet.

In the triangle N. Guadalupe-F-E, the side N. Guadalupe-E $= \dfrac{20{\cdot}3}{\cos 6^\circ 36'} = 20{\cdot}4$ units.

In the triangle N. Guadalupe-D-E, the tangent of angle at base $= \dfrac{-0{\cdot}51}{20{\cdot}4} = -0{\cdot}02500$; the angle of depression $= -1^\circ 26'$.

In the triangle N. Guadalupe-W. Ladera-G, the side W. Ladera-G $= 6292 \times \tan 1^\circ 26' = 157{\cdot}3$ feet.

Therefore, W. Ladera is 222·8 feet above Mejia, and 157·3 feet below N. Guadalupe. If Mejia is 500 feet above the datum plane, then W. Ladera is 722·8 feet and N. Guadalupe 880·1 feet above the same plane. In the same manner any other point on these two photographs may be determined graphically or by calculation.

The point W. Ladera may be determined from one photograph, thus:—

The side Corruscos-Mejia is known from the triangulation, and the bearing of Corruscos-W. Ladera from the field notes. Then in the triangle Corruscos-Mejia-W. Ladera, the angle at Corruscos = 139° 45′. From the photograph VIII. Mejia, the angles 15° 15′ and 10° 36′ may be found as before. Their sum

25° 51′ is the angle at Mejia. The angle at W. Ladera is equal to $180° - (139° 45' + 25° 51') = 14° 24'$. The triangle can now be solved by the ordinary sine-formula, and the distances from Mejia and N. Guadalupe to W. Ladera and their bearings can be determined.

Photographic surveying has also been successfully adopted in other mining districts. Lieut. H. A. Reed in his work on photography applied to surveying reproduces an excellent French photographic map of an area of 13·6 square miles in the vicinity of Sainte-Marie-aux-Mines. The field work was plotted to the scale of $\frac{1}{5000}$. The contours have an equidistance of 5 metres. The field work occupied 10 days, the number of photographic stations was 31, of prints 52, and of points determined 1,400.

In 1880 the Carrara marble quarries were successfully surveyed by L. P. Paganini by the aid of photography, the mountainous character of the district having rendered the use of the plane table inconvenient. The method was also used by V. Pollack in 1890 for a survey required in connection with the construction of a mountain railway at the Eisenerz-Vordernberg iron mines in Styria, and in 1898 by Mr. E. Deville in preparing a map of the Klondyke goldfields from sixteen photographs taken under very adverse conditions from three points at altitudes of 2,870, 3,700, and 3,450 feet.

In Canada the method has also been employed on a number of surveys in the Yukon district, on the Columbian river, and in the Kootenay mining district. It was also used by Mr. A. O. Wheeler in his survey of the Crow's Nest coal area. Some difficulty was experienced in finding camera stations sufficiently commanding to overlook deep valleys. In order to obviate this difficulty Mr. Wheeler conducted traverses up the main waterways. The lines of direction were obtained by theodolite readings, and the elevation was carried through by vertical angle readings at each station. For determining distances some pattern of micrometer or stadia was used. For this purpose a modified form of the Lugeol micrometer was found to give satisfactory results. It consists simply of a telescope, having a bisected object-glass, one of the halves being movable along the line of section by a screw. Two images are formed in the field by the bisected lens. Distances are determined by the number of screw-revolutions necessary to bring, into optical coincidence, the upper and lower targets of the reflected images. The targets are best made of white opal glass set in wooden frames, and are fastened to a rod at a known distance apart: say 15 to 20 links (10 to

13 feet). This is called the base; it is generally furnished with an iron shoe and is stuck in the ground in a vertical position, the target extending side-ways at right angles. Attached to the screw of the movable half of the object-glass is a graduated head, which measures in revolutions and hundredths the section of arc passed over in making the coincidence of the targets. It is merely necessary to find the value of a revolution, in order to enable the distance to be determined for each reading. Tables can readily be constructed so that distances can be taken out by inspection.

Advantages of Photogrammetry.—From the foregoing description it is evident that, with the camera as a surveying instrument, the field-work may be performed with great rapidity. The reduction to a minimum of the time occupied in field-work is the chief advantage of the method. The survey of a length of 3 miles of the Windischgarsten-Spital railway in Austria, covering the entire width of the valley and including the heights on the right side, recorded in 24 pictures by Hafferl, occupied in favourable weather four and a-half hours. With the climatic conditions obtaining at the Arlberg in 1889, it was absolutely impossible to use any other method of surveying the precipitous peaks. It is thus evident that the method is specially useful in the unhealthy malarious districts that a mining engineer is often called upon to survey. It is also well adapted in mountainous and difficult country for laying out rack-railways or aerial wire ropeways. The successful photographic surveys of the Arlberg and of the Rosstrappe mountain in the Harz show that inaccessible regions may easily be surveyed. It follows that it is possible to survey regions that cannot be traversed without danger, such as railways in operation, glaciers, ground above mines where subsidence has set in, or areas to which access is forbidden by the owners. There is, too, the further advantage that additions may at any time be made to the plan without a fresh survey being necessary. The plotting of the survey is not attended by difficulty, as the plan results from an application of the simple method of intersections, whilst the representation of surface-forms and of heights is effected either mechanically or by the use of tabular values that are easily applied. With carefully constructed instruments, the results exceed in precision those obtained with the compass or with the plane-table. As addenda to the plans, the photographs recording the survey will, for the purposes of mine reports, often supply useful information.

APPENDIX I.

EXAMINATION QUESTIONS.

The following examination questions will be found useful to those students who have not the advantage of regular instruction in mine-surveying, affording them a means of personally testing their knowledge:—

1. Give the length of a link, and of a chain. How many chains are there in a mile, and how many acres in a square mile? (*Colliery Managers' Examination, Bristol.*)

2. In chaining over sloping ground, how do you correct for the inclination? Give a simple rule when the inclination is expressed either in angular measure or as a gradient, *e.g.*, 1 in 6, 1 in 15. (*City and Guilds of London Institute, Examination in Mine-Surveying*, 1885.)

3. Describe the miner's dial, and note the improvements recently introduced into its construction. (*Royal School of Mines, Examination in Mine-Surveying*, 1884.)

4. Give a copy of a page of a survey-book recording an imaginary underground-survey. How may you approximately ascertain the date of the workings of an old undated plan? (*Colliery Managers' Examination, West Lancashire*, 1887.)

5. Describe the Henderson dial, and state its supposed advantages over the rack instrument. (*R.S.M.*, 1883.)

6. Give a short description of the miner's dial, with its usual appliances, especially when it is used as a theodolite, the needle being thrown off. (*City Guilds*, 1880.)

7. Describe a Gunter's or land measuring chain. (*City Guilds*, 1881.)

8. What is meant by the term true meridian? Describe a simple method for approximately determining it. (*City Guilds*, 1885.)

9. State the present deviation. In what manner is the deviation usually found to vary from year to year, also in travelling from one locality to another at a considerable distance? (*City Guilds*, 1885.)

10. Sketch on paper the following bearings of a survey:—N. 82° E., 68 links; S. 51° E., 95 links; N. 63° E., 78 links; N. 20° E., 97 links; N. 35° W., 87 links; N. 87° W., 140 links; S. 52° W., 140 links; S. 48° E., 85 links. (*Colliery Managers, Derby.*)

11. Explain the traverse tables. (*Colliery Managers, South Wales.*)

12. Suppose you were driving towards an old waste, which is shown on a plan 20 years old, explain the precautions to be taken as regards the meridian. (*Colliery Managers, Derby.*)

13. You are required to traverse over a level in which rails are laid down. How would you proceed to use an ordinary miner's dial under the circumstances, the dial being without a rack, but supplied with two sets of legs? The only true bearing was one taken in a cross-cut north, at a distance of, say, 5 fathoms off the main level, where the traverse is being made; this cross-cut occurring about half-way in the traverse. Rule a supposed page of your underground book suited to this purpose, and give, say, six drafts or bearings all supposed to be affected by the attraction of the rails, the polarity of the whole being governed by the true bearing in the cross-cut north. If time will permit, insert distances and prove your work by plotting. (*City Guilds*, 1883.)

14. Explain by writing and sketching how to make a loose needle survey. (*Yorkshire College, Leeds*, 1886.)

15. The three sides of a triangle measure 144, 192, and 240 links respectively. Find the area of the triangle in square yards, and the angle opposite to the shortest side. (*City Guilds*, 1885.)

16. What is the area in statute acreage of a triangular field whose sides measure 2,420, 1,860, and 2,005 links respectively? A sketch may be given, but not to scale. Logarithms are recommended for the calculation. (*City Guilds*, 1883.)

17. Explain by writing and sketching how to make and book a fast needle survey. (*Yorkshire College, Leeds*, 1886.)

18. The area, in acres, roods, and poles, is required of an irregular field, which was surveyed by running one line through it from end to end (A to B), with offsets taken as under:—

No plan to be drawn.

	B	
150	15·50 ⊙	0
182	13·00	
	12·48	175
	11·59	55
	9·80	183
280	8·65	
202	3·93	92
	1·50	75
145	0·45	
0	⊙	0
	A	

Length of line, 15·50 chains. (*City Guilds*, 1883.)

19. Give a general description of the theodolite, and explain the method in which you would use it in making an underground-survey. (*City Guilds,* 1887.)

20. What are the special advantages and disadvantages in the use of the ordinary miner's compass as compared with the theodolite? (*City Guilds,* 1887.)

21. The area of a field is determined, by an ordinary chain survey, to be 117 acres 2 roods 33 poles; it is afterwards found that the chain used was only 96·5 links long; what is the true area of the field? (*City Guilds,* 1907.)

22. Calculate the number of cubic yards contained in a rubbish tip standing on level ground, the area of the base of which is 38,755 square feet, and of the level top 18,560 square feet. The average height is 43·3 feet. (*R.S.M.,* 1912.)

23. Work out the following series of levels, showing the height, above the Station A of each point taken :—

Distance.	Back-Sight.	Intermediate	Fore-Sight.	
A	12·63	..	..	
0·40	..	9·16	..	
1·00	..	7·43	..	
1·50	..	5·31	..	
2·00	..	4·06	..	
3·50	..	2·16	..	
4·50	9·06	..	0·42	
5·50	..	7·50	..	
6·50	..	6·15	..	
8·00	..	3·60	..	
9·00	..	2·12	..	
10·50	10·15	..	0·75	
11·20	..	8·70	..	
13·00	..	4·45	..	
14·60	..	..	3·23	

—(*City Guilds,* 1887.)

24. Explain by writing how to level and plot a section. (*Yorkshire College, Leeds,* 1886.)

25. Find the quantity of coal in 1 acre of a seam of the following section :—Top coal, 2 feet 4 inches; band, 0 foot 10 inches; bottom coal, 1 foot 8 inches; total, 4 feet 10 inches, taking the specific gravity of coal at 1·25. (*Colliery Managers, Newcastle-on-Tyne.*)

26. Find the quantity of coal in an acre of a seam 5 feet 6½ inches thick, taking the specific gravity at 1·25. (*Newcastle-on-Tyne.*)

27. If pillars are left 30 by 21, and winnings 32 by 26, what percentage is got in the first working? (*Colliery Managers, Newcastle-on-Tyne.*)

28. How much coal might be expected to be available in an area of 150 acres of a 4-feet seam, allowing one-fifth for faults and waste? (*Science and Art Department, Examination in Mining*, 1884.)

29. The solid contents of a lode are in volume per cent.:—

Galena, ...	30
Zinc-blende, ...	15
Iron pyrites, ...	20
Quartz, ...	35

What is the weight per cubic fathom of the stuff and of its different constituents? (*S. and A. D.*, 1884.)

30. A copper lode is 14 inches thick, containing copper pyrites and fluorspar in the proportion of 2 parts of fluorspar to 1 part of copper pyrites. What is the weight of a square fathom of the lode, allowing one-thirtieth for hollows? (*Rickard.*)

31. A level 7 feet high is driven on a tin lode 8 inches thick, of which one-tenth is oxide of tin, the remainder being quartz. How many tons of tin stuff will be obtained per fathom in length, if the lode is quite solid? (*Rickard.*)

32. In working to the full rise of a seam of which the inclination is 1 in 12 you meet with a rise fault of 10 yards. What will be the length of a rise tunnel to be drawn at the inclination of 1 in 6 between the seam at the low side of the fault, and the seam on its rise side, supposing the fault to be vertical? (*Colliery Managers, West Lancashire*, 1887.)

33. Plot on a scale of 8 fathoms to the inch the following underground traverse, taken with the ordinary miner's "left-hand" dial:—

No.			Bearing.	Distance.			
				fms.	ft.	in.	
							From centre of pp. shaft.
A	..	..	355° 30′	10	4	9	A at crossing of East level.
B	..	..	84° 26′	7	3	2	
C	..	..	92° 04′	8	1	9	C At × cut N.
[D^2	..	..	342° 09′	7	3	0	D^2 END do.
D	..	..	96° 05′	3	5	9	END.

—(*City Guilds*, 1883.)

34. Describe the ordinary method of using the theodolite in making an underground-survey. Also any special method which may be adopted where great accuracy is required. (*City Guilds*, 1887.)

35. Lay down the following underground-survey on the scale of 2 chains to an inch:—

Distance, Chains.		Vertical Inclination.	Horizontal Angles.
Shaft to A	1·90	0° 0′	A = 145° 15′
A B	6·75	4° 35′	B = 177° 30′
B C	4·30	3° 13′	C = 213° 54′
C D	9·77	0° 0′	D = 97° 20′
D E	3·90	6° 46′	E = 130° 13′
E F	6·13	0° 0′	F = 167° 30′
F G	3·01	2° 20′	..

The horizontal angles are those on the left hand of a person travelling in the direction of the survey, and the magnetic bearing of the line F G is 30° east of north. (*City Guilds*, 1887.)

36. The difference of level of two points several miles apart is required with great exactness, and a levelling-instrument of high power is used for the purpose.

Under what circumstances would it be necessary to allow for the spherical form of the earth, and in what manner would you make the proper corrections? (*City Guilds*, 1887.)

37. A colliery waggon way is laid down in a straight line from A, near the shaft, to a point B, in a direction 40° east of north, and is to be extended to join a main line of railway towards the east, running due north and south. The distance from B to the main line is 30 chains, measured due east, and the junction is to be made by a curve 60 chains radius.

Show how the waggon way must be set out, and find what length of line will be required beyond the point B.

In setting out the curve from the straight portion of railway, what offset must be made at the end of the first chain? (*City Guilds*, 1887.)

38. It is intended to sink a shaft on the end of a level driven from Pendarves' shaft, and the following is the survey by J. Budge from the centre of the shaft to the eastern end of the level:—

No.	Bearing.	Distance.			
		fms.	ft.	ins.	
A	357° 00′	7	3	0	from centre of shaft.
B	82° 45′	4	0	6	
C	81° 30′	3	0	0	
D	90° 00′	8	1	1	
E	102° 00′	5	0	0	
F	96° 45′	4	3	0	
G	105° 00′	2	4	5	
H	85° 00′	3	3	0	
J	77° 45′	2	2	7	
K	351° 00′	4	4	0	END.

As absolute accuracy was required a reverse or proof course of dialling was made from the end back to the shaft, with the following results:—

No.	Bearing.	Distance.			
		fms.	ft.	ins.	
A	171° 30′	4	2	10	from eastern END.
B	259° 00′	2	3	0	
C	265° 15′	3	1	6	
D	283° 15′	3	2	0	
E	279° 30′	8	4	3	
F	268° 45′	7	2	0	
G	263° 00′	4	2	0	
H	260° 15′	3	4	8	
J	177° 45′	7	1	10	centre of shaft.

Calculate the distance and bearing, from Pendarves' shaft, of the point at the surface at which the new shaft must be sunk.

39. Sketch and describe a hanging compass, state in which way it is tested and repaired, and describe the manner of its application. (*Tokio University, Japan,* 1879.)

40. Give a short description of the German dial, and what you consider to be its merits or demerits as compared with the English miner's dial. (*City Guilds,* 1880.)

41. Describe the continental method of surveying mines by means of the hanging compass, giving sketches of the instruments employed. (*R.S.M.,* 1886.)

42. What methods have been used to determine the deviation of bore-holes from the vertical? (*Science and Art Department,* 1887.)

43. At the Scotchman's United Mine, Stawell, and in various other places, it has been found that bores made by the diamond drill have deviated so seriously from their initial direction as to imply errors amounting to from 30 to 75 feet in bore-holes of 500 feet. Describe a method of making a survey of such bore-holes, and assuming the errors to have been detected, how is it possible to straighten a bore which has been so deflected as to endanger the safety of the drill? (*R.S.M.,* 1885.)

44. How should the compass be used in exploring for iron ores? (*R.S.M.,* 1887.)

45. Two parallel lodes were discovered at the surface, which was level, 30 yards apart underlying south, the south lode making an angle with the horizon of 65 degrees, the north lode of 52 degrees. Required the perpendicular depth from the surface to their point of intersection; and how far south of the south lode would the centre of a perpendicular shaft have to be placed to come down to the same point? Illustrate by a sketch, not necessarily to scale, but a scale is recommended in order to roughly test the accuracy of the calculations. (*City Guilds,* 1883.)

46. Illustrate in colours the following parts of a finished plan, scale 8 fathoms to the inch:—A road 25 feet wide bounded on each side by a hedge or bank 6 feet wide, showing a gateway, with a cross hedge or two, also a house 30 feet by 20 feet abutting on the road, with a pond adjoining open to the road, but with the hedge continued round its other sides The

pond not to be less than 58 feet long and 25 feet wide, and of an oval but irregular shape. A shaft 10 feet by 6 feet to be shown in one of the fields, surrounded by a burrow or rubbish heap which is to be sketched in with pen and indian ink. The whole drawing to be about 1 foot in length. (*City Guilds*, 1883.)

47. Without the application of a protractor, lay off the following angles from the same base, viz. :—20, 30, and 62 degrees, using a table of natural sines for the purpose. Describe the process. (*City Guilds*, 1883.)

48. In the triangle A B C, the angle A = 37° 45′, B = 72° 15′, and the side A B = 437. Find the sides A C, B C, and the perpendicular distance from C to A B. (*City Guilds*, 1887.)

49. In the triangle A B C, the side A B = 365, A C = 180, and the angle B = 25° 30′. Determine the angles A and C, and the side B C. (*City Guilds*, 1887.)

50. What do you understand by the word traversing? Where is this form of surveying necessary? How would you use an angular instrument in the operation, and how would you check the accuracy of the plotting of the work by trigonometry? (*City Guilds*, 1883.)

51. Describe the true meridian, as compared with the magnetic meridian. How does the adoption of the latter affect plans made from compass observations and added to, as in mine plans, from year to year? (*City Guilds*, 1882.)

52. It is desired to know the exact distance and bearing of an imaginary line between the centre of a perpendicular shaft A and a point B in a level underground, over which it is intended to sink another perpendicular shaft, the dialling of the level commencing from A. Sketch the supposed drafts underground, marking each with its length and bearing, and proceed to describe the best and most accurate method of laying down, at the surface, the line required, and the position of the proposed new shaft over B. (*City Guilds*, 1881.)

*53. Describe the ordinary process of levelling, stating any precautions required to ensure accuracy. (*City Guilds*, 1885.)

54. Work out the following series of levels and plot in the form of a section. Horizontal scale 1 chain to the inch, vertical scale 20 feet to the inch. Datum-line 50 feet.

Distance.	Back-Sight.	Fore-Sight.	
Chains.	Feet.	Feet.	
0·70	1·30	8·85	
1·50	8·85	2·30	
2·45	13·96	5·40	
3·60	5·40	0·52	
4·05	12·62	8·80	
5·40	8·80	1·12	
7·00	2·32	7·05	
9·40	1·33	9·96	
10·20	3·34	5·87	
11·35	5·87	9·10	

—(*City Guilds*, 1885.)

55. Plot, on a scale of 2 chains to an inch, the following survey:—

	Chains.	Bearing.	Inclination Rise.	
A	2·50	119° 45′	..	
B	7·47	137° 16′	3° 50′	
C	13·03	141° 32′	..	
D	3·40	196° 50′	..	
E	6·50	189° 24′	9° 36′	
F	11·66	266° 36′	7° 30′	
G	5·25	272° 22′	..	

—(*City Guilds*, 1885.)

56. A straight draft is required to be driven of uniform inclination between C and G. How must it be set out from each end? (*City Guilds*, 1885.)

57. Describe the method of using the transit-theodolite in order to measure horizontal and vertical angles with great precision. (*City Guilds*, 1885.)

58. Explain the principle of the vernier, and describe the manner in which you would construct a vernier for a circle to read 30 seconds, when the arc is divided into quarter degrees. (*R. S. M.*, 1884.)

59. How may the underground- and surface-surveys of a mine be connected? (*R. S. M.*, 1887.)

60. In a 20-fathom level driven on an east and west lode, underlying north, a winze has been commenced bearing due north, and it is determined to pitch a rise against it in the 40-fathom level; the 30-fathom level not having been driven far enough east for the purpose. How would you determine the exact point in the 40-fathom level to start from? (*R. S. M.*, 1886.)

61. Calculate trigonometrically the bearing and distance of C from the centre of the shaft in the following traverse:—

No.	Angle.	Bearing.	Distance. fms.	Distance. ft.	Distance. ins.	Remarks.
A	0° 00′	351° 29′	10	4	8	From centre of shaft.
B	90° 21′	..	9	3	2	
C	175° 12′	..	12	0	0	END.

—(*R. S. M.*, 1886.)

62. Lay down, on a scale of 1 chain to the inch, the survey given on page 89, representing a four-sided field connected with the shaft of a mine. Calculate the area. (*City Guilds*, 1885.)

63. Plot the following survey, by W. Rickard, of a Cornish mine:—

From pp. line in Williams' shaft at the 60-fathom level.

No.	Bearing.	Distance.			Inclination.	Inclined Length.			Remarks.
		fm.	ft.	in.		fm.	ft.	in	
A	176° 00′	3	2	6	..	..			..
B	77° 30′	4	1	9	..	..			..
C	82° 45′	5	3	3	..	..			..
D	97° 15′	3	2	9	..	..			to Vivian's winze.
E^2	4° 15′	..			F. 75° 45′	10	5	6	..
F^2	285° 00′	7	2	9	..	..			..
G^2	263° 00′	6	3	3	..	..			to Williams' shaft.
H^2	171° 00′	..			R. 74° 11′	5	3	6	Up shaft to pp. line.
E	79° 15′	6	3	6	..	..			..
F	57° 00′	7	2	9	..	..			..
G	35° 30′	2	4	6	..	..			At × cut drive to regain the lode.
H	183° 00′	5	2	9	..	..			On lode.
J	94° 45′	6	4	6	..	..			to John's rise.
K^2	182° 30′	..			R. 67° 30′	11	3	0	Up rise to 50 fm. level.
L^2	84° 15′	5	4	9	..	..			..
M^2	75° 30′	6	2	8	..	..			to Mitchell's shaft.
K	79° 15′	8	5	4	..	..			END.

64. State the nature of the dislocations or *heaves* of lodes, their probable origin, their appearance vertically and on a horizontal plane; and the various rules that have been recommended for regaining the severed portion. (*R.S.M. Examination in Mining*, 1879.)

65. A, B, and C are three bore-holes; the depths of which from the same horizontal plane to a seam of coal are respectively 100, 106, and 108 yards. From A to B is 100 yards, and from A to C 120 yards. The angle in a horizontal plane between A B and A C is 30°. What is the direction of the dip of the seam, and the angle of dip? (*Merivale's Notes and Formulæ.*)

66. Name the permanent adjustments of the transit theodolite, and state how they are made. (*Edinburgh University*, 1888.)

67. Explain fully the process of setting out a tunnel in the driving of which a number of shafts have to be employed. (*Edinburgh University*, 1888.)

68. Suppose you were required to take levels along an underground roadway in order to plot a section showing both roof and floor, state what instruments you would use and how you would proceed. (*Colliery Managers, West Lancashire*, 1887.)

69. State approximately the declination of the magnetic needle for the year 1888, and the average annual variation. How is the declination found to vary in amount as you travel northwards or eastwards? (*City Guilds*, 1388.)

70. Describe the Hedley dial. (*City Guilds*, 1888.)

71. Explain what is meant by the true meridian. How may the true meridian be determined by simple observations of some well-known stars? (*City Guilds*, 1888.)

72. Describe the method of measuring horizontal angles with the theodolite by the process of repetition, and point out the special advantages of this mode of using the instrument. (*City Guilds*, 1888.)

73. Explain the method of reducing and plotting a survey by rectangular co-ordinates. What are the advantages of this method as compared with the ordinary mode of plotting with the scale and protractor? (*City Guilds*, 1889.)

74. What is meant by the term "error of collimation" as applied to a transit-theodolite? How may this error be detected and rectified? Assuming that a considerable error of collimation is allowed to remain uncorrected, in what manner will it affect the measurement of an angle? Can the instrument be used in such a manner as to neutralise this error? (*City Guilds*, 1889.)

75. It is required to determine the position of a distant point, C, in the workings of a colliery, with reference to the surface. For this purpose a survey is made with the theodolite above and underground, from the shaft A to C, and also to a second shaft B, by which means the underground- and surface-surveys are connected. Show how you would carry out the survey so as to obtain the most accurate result.

Give your idea as to the degree of accuracy attainable by this method; and how far it will depend upon the relative positions of the points A, B, and C, and the nature of the surveys between these points. (*City Guilds*, 1889.)

76. Describe the slide rule. (*City Guilds*, 1890.)

77. A line is measured on a uniform slope of 1 in 17. What allowance per chain must be made for the inclination?

78. What is meant by the declination of the needle, and what is the amount of it at Greenwich now, and what was it ten years ago? What precautions must be constantly taken to insure the accuracy of mining plans in consequence of the variation of declination? (*City Guilds*, 1893.)

79. In the case of a mine with only one shaft, which is vertical, and where there is iron, which cannot be removed, in every part, explain how to connect the underground with the surface survey. (*City Guilds*, 1893.)

80. The sides of a triangle are 1,200, 1,100, and 1,000 links in length respectively, what is its area in acres, roods, and perches? Suppose this area to be in a horizontal plane, and to be covered by a seam of coal lying at an inclination of 34° from the horizontal, the thickness of the coal being uniform and measuring, at right angles to the dip, 3 feet in thickness, what is the tonnage of coal in the seam over the above area? (*City Guilds*, 1894.)

81. What errors in direction are likely to arise in surveys made with the magnetic-needle, and how can such errors be controlled and corrected? (*S. and A. D.*, 1895.)

82. In what manner and on what principles can the measurement of the distances and the levels of a series of points in rugged country be expedited? Give examples with sketches of the application of the method. (*University College*, 1895.)

83. What is the declination of the needle at the present time at Greenwich or any other place with which you are acquainted? Will there be any difference, and if so, about how much, between the declination of the needle at Liverpool and at Hull? What was the declination at Greenwich (or other place) ten years ago (approximately)? (*City Guilds*, 1896.)

84. Explain with sketches the construction of a dial such as is generally used in surveying mines. (*City Guilds*, 1896.)

85. What are the requirements of the Coal Mines Regulation Act as to colliery working plans? What further information should they afford in addition to what is legally required? (*Colliery Managers, West Lancashire*, 1896.)

86. On a seam dipping south 1 in 6, what will be the gradient of a road driven north-east? (*S. and A. D.*, 1896.)

87. What is the declination of the magnetic-needle at Camborne at the present time, and to what extent does it differ from the declination at Greenwich? What is meant by the secular variation of the needle? (*Camborne Mining School*, 1897.)

88. A coal seam is 6½ feet thick, with a dip of 1 in 7. What tonnage may be expected from an area 50 chains square? (*S. and A. D.*, 1897.)

89. A heading driven due east in a seam of coal rises at the rate of 2 inches per yard, and a cross-heading at right angles to the former dips at 6 inches per yard. Find the direction of the strike of the seam. (*University of Wales*, 1898.)

90. Draw an open scale of feet to a scale of 17 feet 3 inches to the inch, and long enough to measure 100 feet; and beneath it draw a scale of metres showing decimetres on the same scale. (*City Guilds*, 1898.)

91. Plot the following section to a vertical scale of 10 feet to the inch, and a horizontal scale of 3 chains to 2 inches:—

No.	Total Distance.	Back-sight.	Intermediate.	Fore-sight.	Notes.
	Links.				
1	0	13·27	..	..	B.S. on peg A.
2	55	..	8·15	..	..
3	72	..	8·97	..	..
4	127	9·20	..	1·09	..
5	163	..	6·37	..	..
6	249	..	4·85	..	..
7	308	..	10·26	..	..
8	354	1·87	..	14·75	..
9	396	..	4·15	..	..
10	430	..	4·66	..	..
11	467	..	9·39	..	..
12	553	..	13·24	..	..
13	624	..	..	13·87	F.S. on peg B.

Find the angle of slope from peg A to peg B. (*City Guilds*, 1898.)

92. What methods have been proposed to obtain the greatest amount of light from a safety lamp, where only this kind of lamp can be used, by underground surveyors? (*New South Wales*, 1898.)

93. What are the benefits, present and future, of having the levels of main roads put on the colliery plan? (*New South Wales*, 1898.)

94. In a closed traverse, how could you prove that the interior angles were correct? (*New South Wales*, 1898.)

95. Construct a diagonal scale of 5 fathoms to the inch, long enough to measure 30 fathoms, and showing fathoms, feet, and inches. (*City Guilds*, 1904.)

96. Calculate the co-ordinates, and plot by co-ordinates the following theodolite survey of a cross-cut; theodolite graduated to the right-hand, set originally pointing due north; measurements in links. Scale, 3 chains to the inch. Calculate length and bearing of line required to close the survey:—

No.	Meridian Angle.	Distance.	No.	Meridian Angle.	Distance.
1	42° 26′	596·5	9	307° 40′	369·4
2	42° 40′	468·5	10	306° 20′	969·5
3	43° 00′	963·4	11	306° 17′	448·4
4	42° 54′	735	12	306° 34′	435·4
5	42° 19′	1228·5	13	306° 12′	279·25
6	43° 43′	778·5	14	221° 11′	650·8
7	310° 03′	237	15	220° 30′	557·5
8	312° 58′	353	16	180° 22′	639

—(*City Guilds*, 1898.)

97. Plot the following survey made with a right-handed theodolite, the instrument being pointed due north at the first station. All measurements in feet and inches. The mouth of the upper level was found to be 117·38 feet above the lower. Scale, 40 feet to the inch:—

Station Lines.	Meridian Angle.	Distance.		Remarks.
		Ft.	ins.	
A B	349° 23′	79	6	B is at mouth of lower drift, 4 feet wide.
B C	316° 05′	109	0	..
C D	343° 20′	41	0	D in vein, 4 feet 3 inches wide.
D E	57° 22′	65	0	Vein 4 feet 8 inches wide.
E F	32° 13′	104	6	Vein 5 feet 3 inches wide.
F G	27° 38′	143	0	G at centre of winze, 4 feet 9 inches square.
A H	19° 32′	308	0	H is at mouth of upper drift, 4 feet 3 inches wide.
H J	0° 27′	59	6	..
J K	346° 49′	67	6	K is in vein, 3 feet 9 inches wide.
K L	22° 29′	44	0	L at centre of winze, 4 feet 9 inches square

Determine direction and angle of dip of winze. (*City Guilds*, 1898.)

98 Draw an open scale, long enough to measure 50 feet, of 9 feet 4 inches to the inch. (*City Guilds*, 1899.)

99. Draw a diagonal scale of 2 feet 3 inches to the inch, long enough to measure 15 feet, and showing feet and inches. (*City Guilds*, 1899.)

100. The three sides of a triangular field measure 197, 125, and 89 yards respectively; calculate its area in acres, etc. (*City Guilds*, 1899.)

101. Plot the following traverse survey, and determine the length and bearing of the line joining points A and E:—

	Meridian Angle.	Length.
A B . . .	226°	2 chains 78 links.
B C . . .	123°	2 „ 40 „
C D . . .	242°	1 „ 82 „
D E . . .	172°	2 „ 95 „

Plot to a scale of 2 inches to the chain. (*City Guilds*, 1899.)

102. Explain how you would set out a right angle by means of an ordinary surveyor's chain. (*City Guilds*, 1899.)

103. An embankment on level ground is 100 yards long, 17 feet wide on top, and 10 feet high, the sides have a batter of 1 in 3. Calculate its cubic contents. (*City Guilds*, 1899.)

104. A coal seam dipping 1 in 10 is thrown down by a fault, inclined 80° to the horizontal, the vertical throw being 150 feet; a drift is started from the upper portion of the seam to the down-throw portion with a fall of 3½ inches to the yard. How long will the drift be? (*City Guilds*, 1899.)

105. A man 5 feet 10 inches high walks from an observer lying on the ground towards a chimney until the top of his head is seen to be exactly in line with the chimney top; his distance from the observer is 16 paces, and from the chimney 107 paces. What is the height of the chimney? (*City Guilds*, 1899.)

106. A lighthouse is seen on an island about half-a-mile from a flat sandy shore. How will you determine its exact distance using only a surveyor's chain and ranging poles? (*City Guilds*, 1899.)

107. A tunnel driven into a hillside rises 1 in 15; it cuts a coal seam dipping 20° towards the tunnel mouth; the width of the seam measured along the floor of the tunnel is 19 links. How many tons of ordinary bituminous coal will the seam contain per acre? (*City Guilds*, 1899.)

108. A seam of mineral dips 20° towards N. 39° E.; at what bearing should a road be set out in the seam so as to have a grade of 2½ inches to the yard? (*City Guilds*, 1899.)

109. How would you survey with a plain miner's dial in a mine in which there are much iron machinery, rails, pipes, etc.? Give a page from an imaginary survey book with at least eight drafts, and show how you would calculate the traverse from them in illustration of your answer. (*City Guilds*, 1899.)

110. Explain the subtense method of determining distances. (*City Guilds*, 1899.)

111. A curve of 15 chains radius is to be set out to connect a main level with a cross-cut at right angles to it; describe in detail how this should be done. (*City Guilds*, 1899.)

112. Give a page from an imaginary level book, showing at least twelve readings obtained by four settings of the instrument; work out and plot the section to any convenient scale. (*City Guilds*, 1899.)

113. The following survey was made by double foresight method with right-handed theodolite, the instrument pointing due N. at the first station and being brought back to zero after each reading. Measurements in links. Calculate the survey and plot it by co-ordinates. Scale 2 inches = 1 chain.

No.	Observed Theodolite Readings.	Distances.	No.	Observed Theodolite Readings.	Distances.
1, .	180° 00′	306	5, .	61° 12′	143
2, .	176° 21′	203	6, .	170° 21′	53
3, .	148° 51′	73	7, .	186° 21′	112
4, .	183° 54′	129	8, .	121° 39′	193

In the above question calculate the length and bearing of the line required to close the survey, and the area enclosed by it and by the survey traverses. (*City Guilds*, 1899.)

114. Work out the following series of levels and plot in the form of a section. Horizontal scale 1 chain to an inch. Vertical scale 20 feet to an inch. Datum line 50 feet.

Distance.	Back-sight.	Fore-sight.
Chains.	Feet.	Feet.
0·70	1·30	8·85
1·50	8·85	2·30
2·45	13·96	5·40
3·60	5·40	0·52
4·05	12·62	8·80
5·40	8·80	1·12
7·00	2·32	7·05
9·40	1·33	9·96
10·20	3·34	5·87
11·35	5·87	9·10

—(*Nova Scotia Managers' Exam.*, 1899.)

115. Lay down the following underground survey on the scale of two chains to 1 inch :—

Distance.	Chains.	Horizontal Angles.
Shaft to A	1·90	A 145° 15′
A „ B	6·75	B 177° 30′
B „ C	4·30	C 213° 54′
C „ D	9·77	D 97° 20′
D „ E	3·90	E 130° 13′
E „ F	6·13	F 167° 30′
F „ G	3·01	..

The horizontal angles are those on the left hand of a person travelling in the direction of the survey, and the magnetic bearing of the line F G is 30° east of north. Also reduce the above readings to one meridian, and plot your proof. Explain how you would correct the above survey if made in a seam considerably inclined. (*Nova Scotia Managers' Exam.*, 1899.)

116. Plot the following to a scale of 1 chain to an inch :—

N 31° W, 275 links.
N 60° E, 610 „
S 30° E, 280 „

Find the length of ' tie " line, and calculate the area, in acres, of the enclosed figure. (*New South Wales Department of Public Instruction*, 1899.)

117. Down a shaft underlying south, the following were measured :—

Hade.	Distance. Feet.
10° 30′	195
15° 45′	520
20° 00′	320
5° 30′	265

You are required to find (*a*) the depth of a vertical shaft proposed to be sunk on the south side to intersect the termination of the survey, and (*b*) the horizontal distance between the tops of the two shafts. Scale 132 feet to an inch. (*New South Wales*, 1899.)

118. Plot the following to a scale of 2 chains to an inch, and find the bearing and length of the seventh set to tie with the beginning of the first set :—

S 47¼° E, 340 links.
S 79½° W, 160 „
S 30¾° E, 424 „
N 62½° W, 710 links.
N 41° E, 230 „
N 62½° W, 340 „

(*New South Wales*, 1899.)

119. Find the uniform gradient of a road in which the following levels were taken :—

Back-sight.	Fore-sight.	Distance.
Feet.	Feet.	Links.
11·95	9·77	230
9·77	4·88	425
4·88	1·94	632
1·94	4·08	245
12·05	5·05	627
5·05	5·72	110
5·72	1·92	730
1·92	2·73	260

Express the gradient in inches per yard. (*New South Wales*, 1899.)

120. The three sides of a triangle measure 370, 295, and 466 yards respectively; draw the triangle to a scale of 100 feet to the inch, and calculate its area in acres, etc. (*City Guilds*, 1900.)

121. An embankment is 30 chains long, the top is 10 feet wide, one side has a slope of 55° and the other of 50° to the vertical. The ground and top of the embankment are level, and the embankment is 13 feet high at the centre. Calculate its contents in cubic yards. (*City Guilds*, 1900.)

122. Draw a scale of $\frac{1}{27}$ to show feet, and long enough to measure 20 feet. (*City Guilds*, 1900.)

123. Plot the following traverse lines, all starting from one central point; scale 25 feet to 1 inch :—

1, . . .	N. 77° E.	64 feet.
2, . . .	N. 21° 30′ W.	1 chain 12 links.
3, . . .	N. 15° 15′ E.	15 yards.
4, . . .	S. 29° 20′ W.	187 links.
5, . . .	S. 56° 45′ E.	14 fathoms.

(*City Guilds*, 1900.)

124. How many tons of coal per acre will there be in a seam 3 feet 9 inches thick, dipping at an angle of 9°, allowing 20 per cent. deduction for faults, etc.? (*City Guilds*, 1900.)

125. In the ordinary miner's dial the E. mark is to the left of the N. Why is this? (*City Guilds*, 1900.)

126. Explain the terms diurnal variation, dip, declination, and secular variation of the magnetic-needle. (*City Guilds*, 1900.)

127. You have to measure the width of a deep river about 150 yards wide, and your only measuring instrument is an ordinary chain. How would you proceed? (*City Guilds*, 1900.)

128. A vertical shaft is 400 feet deep. Half way down it an incline starts from it, which meets a drift dipping towards the shaft bottom at a grade of 2 inches to the yard, at a distance of 4 chains from the shaft, this distance being measured along the floor of the drift. Find the length and inclination (in degrees and minutes) of the incline. (*City Guilds*, 1900.)

129. A theodolite is set in up line with two telegraph poles, 150 feet from the nearer pole and 450 feet from the further pole. The top of the further pole subtends an angle of 18°, the line of sight passing through a hole exactly half way up the nearer pole. Required the heights of the two poles, the theodolite standing 5 feet above the ground. (*City Guilds*, 1900.)

130. A seam of mineral dipping 12° is thrown down 200 feet by a vertical fault; an inclined drift is started from the top of the down-throw and cuts the seam 400 feet horizontally from the fault. Required length and dip of the inclined drift. (*City Guilds*, 1900.)

131. Calculate the co-ordinates of the following traverse survey, calculate the length and bearing of the line G A, and plot by co-ordinates to a scale of 1 chain to the inch :—

Traverse survey of polygonal area made by double foresight method with a right-handed theodolite reading to 30 *seconds; the theodolite was originally set in the true meridian, true north reading* 360° 00′ 00″.

Line.	Observed Angle.	Length in Links.
A B .	14° 48′ 00″	245
B C .	198° 06′ 30″	310
C D .	284° 01′ 30″	480
D E .	200° 12′ 30″	709
E F .	271° 33′ 30″	430
F G .	268° 01′ 30″	607
G A		

—(*City Guilds*, 1900.)

132. Calculate the area of the above polygon in acres, etc., by the method of co-ordinates. (*City Guilds*, 1900.)

133. A bed of mineral dips 58° (to the horizontal), the direction of full dip being S. 24° 56′ E. What will be the dip of a road running N. 80° 20′ W.? (*City Guilds*, 1900.)

134. Two horizontal levels are driven in a vein dipping 77° towards N. 56° E., the levels being 200 feet apart vertically. A flat winze in the vein connecting the levels is 446 feet long. What is its dip and bearing? (*City Guilds*, 1900.)

135. How would you proceed to level along an inclined drift about 3 feet 6 inches high, and inclined about 40°? (*City Guilds*, 1900.)

136. Draw a section of the telescope used in the ordinary dumpy level, showing clearly the path of the rays of light through it. (*City Guilds*, 1900.)

137. Under what circumstances must a correction for the earth's curvature be applied in levelling? State a formula for this correction. (*City Guilds*, 1900.)

138. Sketch and explain the action of the tangent screw and clamp, as applied to any part of a theodolite. (*City Guilds*, 1900.)

139. Describe a method of connecting underground and surface traverses through a single shaft, the use of the magnetic-needle being inadmissible. (*City Guilds*, 1900.)

140. A coal seam is proved by three bore-holes, A, B, and C, at the following depths:—A is 200 yards deep, B 250 yards, and C 280 yards. The distance between A and B is 430 yards, between A and C 740 yards, and between B and C 960 yards. Find the direction and inclination of the full dip of the seam, assuming that the surface of the ground at the bore-holes is level. (*New South Wales*, 1901.)

141. How would you proceed to mark a survey-station underground where the roof is bad? (*University of Wales*, 1901.)

142. Make out an imaginary page from a level book, showing twelve readings taken with four settings of the instrument over undulating ground. Work out and plot the section. (*City Guilds*, 1901.)

143. Three bore-holes, A, B, and C, intersect a seam of coal; they are situated at the angles of an equilateral triangle, whose sides are 300 yards in length. B is N. 17° 20′ E. of A; and C is to the westward of the line A B. A cuts the seam at a depth of 175 feet, B at a depth of 342 feet, and C at a depth of 240 feet. Determine the direction and amount of dip of the coal seam. (*City Guilds*, 1901.)

144. What is meant by a traverse survey? Illustrate your reply by a diagram. Show the system you would use for the field book of a theodolite traverse. (*Gold Coast Examinations for Surveyor's Licence*, 1902.)

145. Describe the construction of a prismatic compass; state its uses and the objections, if any, to its employment underground. (*City Guilds*, 1902.)

146. Explain how and why the aneroid barometer can be used for rough levelling. (*City Guilds*, 1902.)

147. Describe the process of setting out, with accuracy, a long tunnel in a mountainous region. (*Camborne Mining School*, 1904.)

148. Describe a method of connecting underground and surface traverses through a single shaft somewhat out of repair. (*Camborne Mining School*, 1904.)

149. The co-ordinates of two points A and B are as follows:—(A) Latitude N. 463 links. Departure W. 249 links. (B) Latitude S. 157 links. Departure W. 1,348 links. Calculate the length and bearing of the line A B. (*City Guilds*, 1904.)

150. You have a miner's dial, and you find that when one end of the needle marks due N., the other end reads S. 3° 30′ W. To what faults of construction may this be due? Can you use the dial in this state for surveying, and, if so, how? (*City Guilds*, 1904.)

151. Explain the principle of the vernier as applied to an ordinary theodolite. (*City Guilds*, 1904.)

152. What is meant by the "line of collimation"? Illustrate your answer by giving an imaginary page from a level-book, showing 9 readings taken with 4 settings of the dumpy level, reduced by the method of collimation. (*City Guilds*, 1904.)

153. A, B, and C are three bore-holes piercing the same bed of coal at depths respectively 390, 900, and 474 feet. The height of A above a common datum is 150 feet, of B 180 feet, and of C 114 feet. From A to B is 2,400 yards, A to C is 880 yards, and B to C is 2,300 yards. At what depth would a main shaft X, put down within the triangle formed by the three bore-holes, intersect the seam; A X being 1,953 yards, B X 450 yards, and the height of X 423 feet above the datum? (*Colliery Managers, Western Australia*, 1904.)

154. A mineral vein dips due south at an angle of 67° to the horizontal; an incline is set off running S. 34° W. What will be its gradient in inches to the yard? (*City Guilds*, 1905.)

155. Two straight lengths of a railway track make with each other an angle of 147°. Show how you would connect them by means of a curve of 12 chains radius, the ground being practically level. (*City Guilds*, 1905.)

156. Work out and plot the following section on a horizontal scale of 50 links and a vertical scale of 5 feet to the inch:—

No.	Back-sight.	Intermediate.	Fore-sight.	Distance.
				Chains.
1	4·70	..	..	..
2	..	5·69	..	0·29
3	..	5·93	..	0·59
4	..	7·74	..	1·00
5	..	9·46	..	1·29
6	5·93	..	13·81	1·70
7	..	5·04	..	2·00
8	..	3·89	..	2·25
9	..	3·74	..	2·80
10	..	5·99	..	3·37
11	..	5·82	..	4·00
12	..	..	6·59	5·13

(*City Guilds*, 1905.)

157. What are the provisions of the Coal Mines Regulation Acts as to plans and surveys, and as to plans of abandoned mines? (*Colliery Managers, S. District,* 1905.)

158. Describe fully the methods of making an underground survey with the magnetic-needle and also with the fixed-needle, and show your methods of booking in each case and how you would connect the underground survey with the surface plan, and the precautions you would take to avoid errors through a variation of the magnetic meridian, including a survey of new workings upon an old plan, and how you would find the magnetic meridian at the time of such survey. (*Colliery Managers, S. District,* 1905.)

159. In making an extensive levelling, what amount of difference per mile should be allowed for the curvature of the earth? (*Colliery Managers, S. District,* 1905.)

160. Draw a plan of the plain miner's dial, indicating how it is graduated, and explain the reason for this graduation. (*City Guilds,* 1906.)

161. Calculate the co-ordinates of the following traverse survey, and plot by co-ordinates to a scale of 2 chains to the inch :—

No.	Bearing.	Distance in Links.
1,	S. 0° 00′	545
2,	S. 23° 15′ W.	501
3,	S. 19° 05′ E.	199½
4,	S. 51° 10′ W.	301½
5,	S. 62° 35′ E.	708
6,	N. 30° 07′ E.	493
7,	N. 32° 07′ E.	598
8,	N. 23° 50′ W.	525
9,	N. 64° 18′ W.	681¾

162. Calculate the area enclosed by the above traverse. (*City Guilds,* 1906.)

163. What precautions would you take in making (1) a fast needle survey (2) a loose needle survey? What kind of lamp would you use in each case, and why? (*Colliery Managers, S. District,* 1907.)

APPENDIX II.

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